ERDC/CERL TR-01-55

Construction Engineering Research Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Site Evaluation for Application of Fuel Cell Technology

U.S. Coast Guard Academy, New London, CT

Franklin H. Holcomb, Michael J. Binder, William R. Taylor, J. Michael Torrey, and John F. Westerman

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Foreword

This study was conducted for the U.S. Coast Guard (U.S.C.G.) Air Station Cape Cod, MA under Military Interdepartmental Purchase Request (MIPR) No. W31RYO833-60270, Work Unit V69, "New TI Design of PAFC Power Plants." The technical monitor was Steve Allen, U.S. Coast Guard R&D Center.

Jim Candee, of the U.S.C.G. Research and Development Center, was the primary point of contact for the site visits, provided contact with appropriate site personnel, and collected various needed information such as energy bills, site drawings, etc. His efforts were instrumental in completing this site evaluation. George Stephanos also provided important input to this investigation.

This report documents work done at the U.S. Coast Guard Academy, New London, CT. The work was performed by the Energy Branch (CF-E), of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Michael J. Binder. Part of this work was done by Science Applications International Corporation (SAIC) under. contract No. DACA88-98-003. J. Michael Torrey and John F. Westerman are associated with SAIC. The technical editor was William J. Wolfe, Information Technology Laboratory. Larry M. Windingland is Chief, CEERD-CF-E, and L. Michael Golish is Chief, CEERD-CF. The associated Technical Director was Gary W. Schanche. The Acting Director of CERL is Dr. Alan W. Moore.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL John Morris III, EN and the Director of ERDC is Dr. James R. Houston.

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1 Introduction

Background

Fuel cells generate electricity through an electrochemical process that combines hydrogen and oxygen to generate direct current (DC) electricity. Fuel cells are an environmentally clean, quiet, and a highly efficient method for generating electricity and heat from natural gas and other fuels. Air emissions from fuel cells are so low that several Air Quality Management Districts in the United States have exempted fuel cells from requiring operating permits. Today's natural gas-fueled fuel cell power plants operate at electrical conversion efficiencies of 40 to 50 percent; these efficiencies are predicted to climb to 50 to 60 percent in the near future. In fact, if the heat from the fuel cell process is used in a cogeneration system, efficiencies can exceed 85 percent. By comparison, current conventional coal-based technologies operate at efficiencies of 33 to 35 percent.

Phosphoric Acid Fuel Cells (PAFCs) are in the initial stages of commercialization. While PAFCs are not now economically competitive with other more conventional energy production technologies, current cost projections predict that PAFC systems will become economically competitive within the next few years as market demand increases.

Fuel cell technology has been found suitable for a growing number of applications. The National Aeronautics and Space Administration (NASA) has used fuel cells for many years as the primary power source for space missions and currently uses fuel cells in the Space Shuttle program. Private corporations have recently been working on various approaches for developing fuel cells for stationary applications in the utility, industrial, and commercial markets. Researchers at the U.S. Army Engineer Research and Development Center (ERDC), Construction Engineering Research Laboratory (CERL) have actively participated in the development and application of advanced fuel cell technology since fiscal year 1993 (FY93). CERL successfully executed several research and demonstration work units with a total funding of approximately $55M.

CERL researchers have developed a methodology for selecting and evaluating application sites, have supervised the design and installation of fuel cells, and have actively monitored the operation and maintenance of fuel cells, and com-

piled "lessons learned" for feedback to manufacturers. This accumulated expertise and experience has enabled CERL to lead in the advancement of fuel cell technology through major efforts such as the DoD Fuel Cell Demonstration, the Climate Change Fuel Cell Program, research and development efforts aimed at fuel cell product improvement and cost reduction, and conferences and symposiums dedicated to the advancement of fuel cell technology and commercialization.

This report presents an overview of the information collected at the U.S. Coast Guard Academy, New London, CT, along with a conceptual fuel cell installation layout and description of potential benefits the technology can provide at that location.

Objective

The objective of this work was to evaluate the U.S. Coast Guard Academy as a potential location for a fuel cell application.

Approach

On 27 and 28 October 1998, USACERL and SAIC representatives visited the United States Coast Guard (U.S.C.G.) Academy to investigate it as a potential location for a 200 kW fuel cell. This report presents an overview of information collected at the Site along with a conceptual fuel cell installation layout and description of potential benefits. The Appendix to this report contains a copy of the site evaluation form filled out at the Site.

Units of Weight and Measure

U.S. standard units of measure are used throughout this report. A table of conversion factors for Standard International (SI) units is provided below.

1 ft	=	0.305 m
1 mile	=	1.61 km
1 acre	=	0.405 ha
1 gal	=	3.78 L
°F	=	°C (X 1.8) + 32

2 Site Description

The U.S. Coast Guard Academy is located in New London, CT on the west bank of the Thames River. The ASHRAE design temperatures at the Academy are 9 and 85 °F. Extreme temperatures range from 5 to 88 °F. The Academy is a 4-year institution for young men and women working toward a Bachelor of Science degree and a commission as an officer in the U.S Coast Guard. Training for cadets began in 1876 and originally was located on a series of ships up until the Academy moved to its present location in 1932. Enrollment at the Academy is approximately 850 cadets. Also located at the Academy is the Coast Guard Leadership Center where Coast Guard officers of every rank train for higher leadership roles.

The Academy is comprised of approximately 30 buildings. These include housing/dormitory facilities, lecture halls, office buildings, athletic facilities, a library, a chapel, Officer's Club, medical clinic, etc. Most of the campus buildings are supplied electricity through a central electric meter; however, a few buildings are individually metered. Natural gas is available only at certain buildings throughout the campus. Low sulfur No. 6 fuel oil is used at the heating plant.

Several building applications were investigated as potential sites for a 200 kW fuel cell. The principal buildings investigated include:

- Heating Plant
- Roland Hall (gymnasium/athletic facility)
- Waesche Hall (library and museum)
- Chase Hall (cadet dormitory and mess hall).

Heating Plant

The central heating plant was evaluated as a potential fuel cell location. Fuel cell thermal output could be used to pre-heat boiler make-up water. The heating plant has three Bigelow Company boilers; two are rated at 28,500 lb/hr and the other is rated at 14,000 lb/hr. One of the large boilers is used in the winter while the small boiler is used in the summer as well as to back up the large boiler during high steam demand periods. The boilers operate exclusively on No. 6 low sulfur fuel oil.

The heating plant just went through an upgrade of various systems including reinsulation of the deaerator and oil separators and a new condensate return heat exchanger. In addition, condensate return lines were repaired and new steam traps were installed throughout the steam distribution loop. Due to the reduction in steam losses as a result of these improvements, make-up water requirements for the boilers were reduced significantly from 600 gal/hr to approximately 100 gal/hr. There is no natural gas available at the heating plant. Studies to evaluate natural gas for dual fuel capability at the boilers indicated that it would not be cost effective due to both the relative cost of No. 6 fuel oil and the significant investment required to bring natural gas to the building. The lack of natural gas availability and the small make-up water requirement for the boilers resulted in eliminating the heating plant from further consideration as a potential fuel cell site.

Roland Hall

Roland Hall is a 127,000 sq ft athletic facility that houses an indoor swimming pool, gymnasium, locker rooms, and a multipurpose track, which is also used for indoor tennis, softball, soccer, etc. This facility has the largest end-user thermal load of any of the Academy buildings. On the south side of Roland Hall, there is a large solar panel array that was recently decommissioned. Steam from the heating plant is used in the facility for domestic hot water (DHW), including showers and laundry, space heating and pool heating. The building has two principal mechanical rooms. Room 259 contains the primary steam to hot water heat exchanger used for distributing space heating throughout the building. Room 258 contains a steam heat exchanger for heating two 1400-gal DHW storage tanks and also for space heating. The pool is heated primarily by a Dectron dehumidifier unit that uses waste heat from a condenser. Steam is used to heat the pool only when the Dectron unit cannot keep up with the heating requirement. There is currently no natural gas located at Roland Hall. A natural gas line would need to be brought in if the fuel cell were to be located at this facility.

Waesche Hall

Waesche Hall houses the Coast Guard Museum, the library, Admissions and the Public Affairs office. It is an approximately 68,000 sq ft, three story building that was built in 1970. There is presently no natural gas at the building, but there is a gas line on nearby Deshon Street. Waesche Hall is one of the buildings at the Academy that is individually metered for electricity. Its peak monthly load ranges from 294 to 408 kW, but its minimum load drops below the 200 kW

capacity of the fuel cell. Load data was obtained from the electric utility and is discussed later in the report. To site the fuel cell here, it would be beneficial to either consolidate adjacent building loads under 1 meter, or contract with the electric utility to credit excess electricity sent to the utility grid against other buildings' electric bills. Waesche Hall is heated using electric resistance heaters located in the building duct work. If fuel cell thermal output could be used to displace this electric heating load, energy savings would be credited at the higher cost of electricity as compared to typically lower cost natural gas or steam-based space heating.

Chase Hall

Chase Hall contains the majority of Cadet dormitory housing as well as a mess hall and administrative offices. Instantaneous hot water generators, which operate off of the steam loop, were recently installed in the building to meet the mess hall and some of the DHW loads (thus reducing the potential thermal load). There are two large (1100 gal) DHW tanks in Chase Hall, but they are located a significant distance from each other making it difficult to interface both tanks with a fuel cell. Although there is a natural gas line located in Chase Hall, its location at the kitchen makes for a long and difficult piping run over to the hot water storage tanks where the fuel cell would be located.

Summary of Four Building Options

Of the four buildings that were originally considered potential fuel cell application sites, Roland Hall and Waesche Hall were considered the most promising applications. Each building, however, presents a significant issue to be resolved. Roland Hall would need to have a gas line run to it, a length of more than 200 yards from the street. Waesche Hall would need to have a gas line brought in from the street although this is not a major obstacle due to its close proximity to the street. The primary issue with Waesche Hall is that the electric output of the fuel cell exceeds the building load at night when the building is not occupied.

Site Layout

Figure 1 shows a base map of the U.S. Coast Guard Academy. The Academy overlooks the Thames River, much of it sitting on granite and hilly terrain. The

granite soil is significant in that it makes the installation of new natural gas lines more difficult.

Roland Hall

Figure 2 shows an overall site layout of the athletic facility. The 127,000 sq ft building consists of five floors. The two mechanical rooms are located on the second floor. On the south side of the building is an abandoned solar panel array that sits next to a parking lot. The natural gas line would need to be brought in from this end of the building.

Waesche Hall

Figure 3 shows a building layout of Waesche Hall. The museum is located near the entrance on the south side of the building. The mechanical room is located on the lower level.

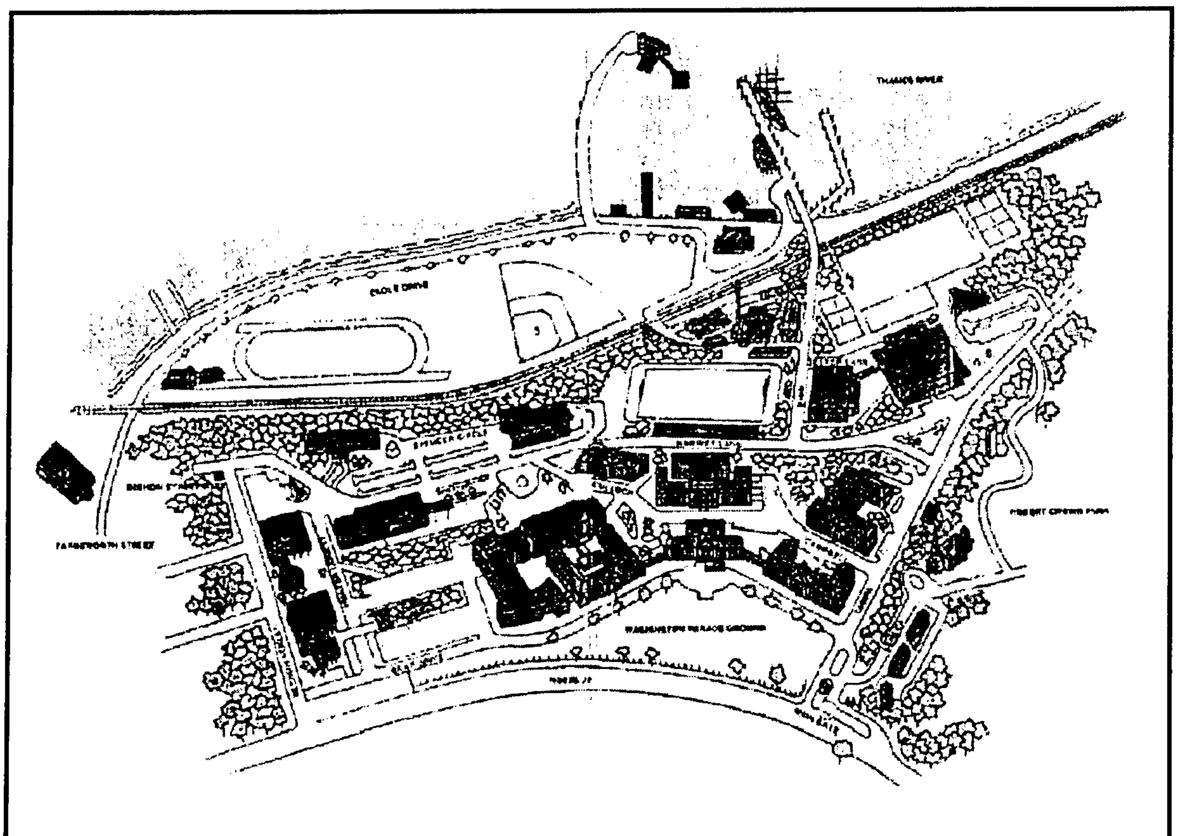

Figure 1. U.S. Coast Guard Academy site map.

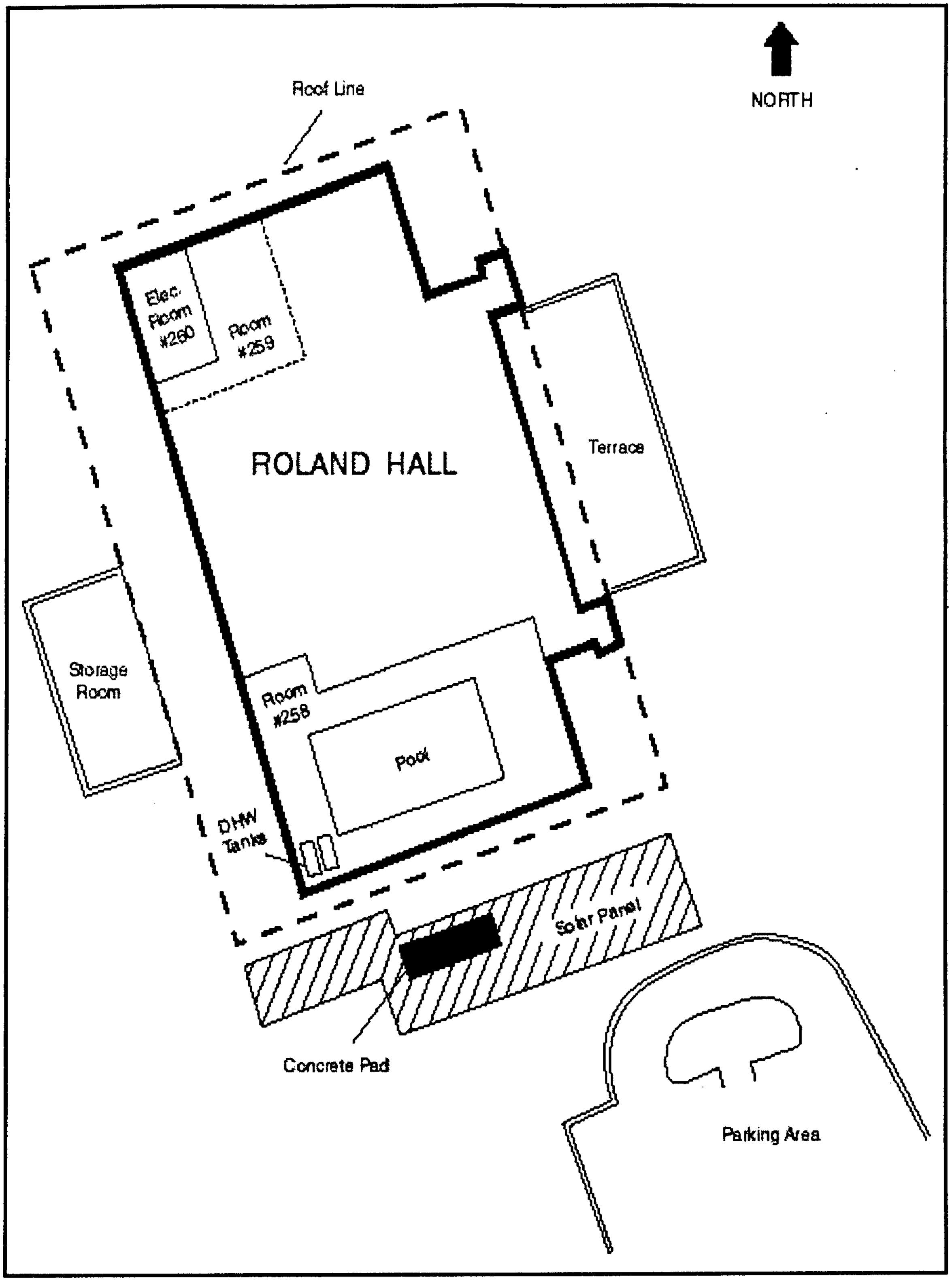

Figure 2. Roland Hall site layout.

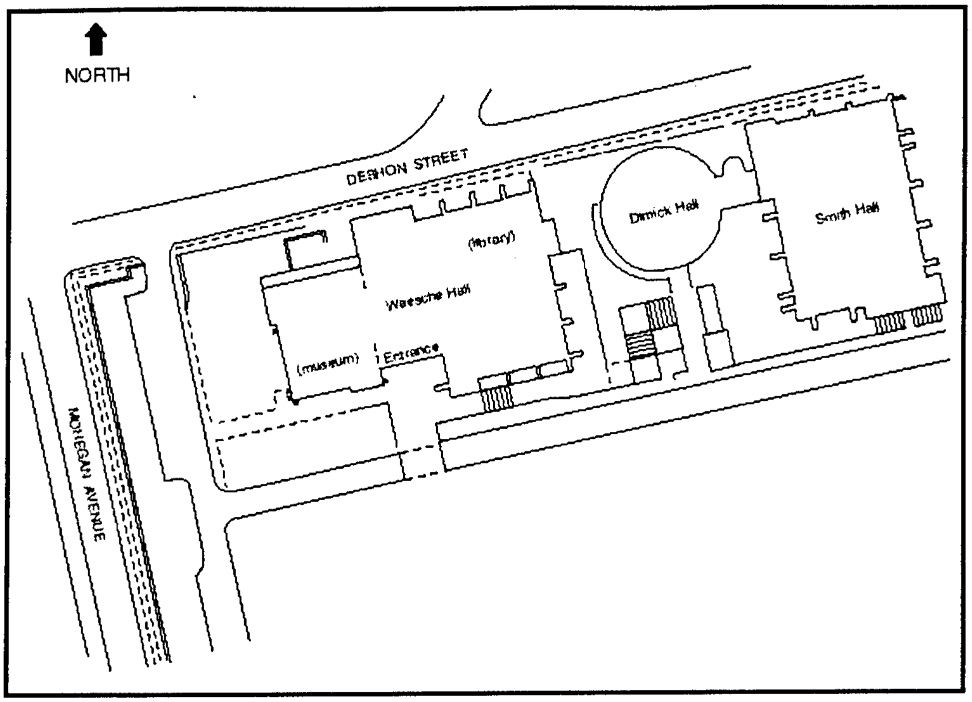

Figure 3. Waesche Hall site layout.

Electrical System

Electricity at the Academy is distributed on base to individual buildings at 4160 V. There are five main electric meters including the main meter for the Academy, Waesche Hall, Smith Hall, the Rowing Center, and the Child Development Center. Each building has its own transformer to serve the individual loads of the facility.

Roland Hall

There is a 208/4160 V, 750 kVA transformer located inside the electrical room (room #260), which is located next to mechanical room #259. There is currently no 480 V power in Roland Hall. To interface with the fuel cell, a new 480 V transformer would need to be installed and connected to either the 208 V side of the existing transformer or directly into the 4160 V grid.

Waesche Hall

There is a 480/4160 V, 1500 kVA transformer located on the north side of the building. The electric room located next to the mechanical room has 16 panels, one of which is a spare that could be used for interfacing with the fuel cell.

Steam/Hot Water System

Steam to hot water heat exchangers are located in most buildings throughout the Academy and are fed by the heating plant's steam distribution loop. Steam is generated by three Bigelow Company boilers, two of which are rated at 28,500 lb/hr, and one at 14,000 lb/hr. The steam generated gets distributed at ~375 °F and 90 psig. It is reduced to 50 psig for distribution within a building and then reduced again to 15 psig for the steam/hot water heat exchangers. One of the large boilers operates during the heating season with the small boiler brought on line to service high demand periods. The small boiler operates exclusively during the nonheating season. As mentioned previously, the heating plant and distribution loop systems were upgraded to include new insulation, steam traps, and repair of piping. Make-up water requirements were reduced significantly from ~600 gal/hr to ~100 gal/hr. The fuel cell would typically interface with a boiler plant by preheating the make-up water. Since the fuel cell can supply significantly more than the present requirement (25 gal/min or 1500 gal/hr), and no natural gas is available nearby, the heating plant was eliminated from further consideration for a fuel cell as stated previously.

Roland Hall

DHW in Roland Hall is provided by steam-fed hot water storage tanks. The two cylindrical tanks measure 4 ft, 9 in. wide x 14 ft long, including insulation. Storage tank capacity is estimated at 1400 gal. The two tanks feed the DHW loads for showers/sinks as well as hot water for the four, 50 lb commercial washers used in the laundry. The solar system previously provided building hot water, but it has now been completely disabled.

Waesche Hall

Hot water is provided in the building by an electric boiler. The Reimers Electra Steam, Inc. boiler (Model R150) is rated at 150 kW and runs on 480 V, 3-phase electricity. Hot water is used primarily for the bathrooms.

Space Heating System

Most buildings at the Academy are heated by the steam distribution loop.

Roland Hall

The primary distribution point for space heating is located in mechanical room #259. There are 18 air handlers with a total capacity of 205,000 cu ft/min (cfm). Seven of the air handlers have steam pre-heaters, which boost up the incoming temperature for the 100 percent make-up air required to serve the locker rooms. Mechanical room #258 has four air handlers, all of which have steam boosters.

Waesche Hall

There is currently no steam or natural gas available at Waesche Hall. Space heating is provided through resistance heating elements located within the VAV distribution boxes throughout the building. Waesche Hall has three distribution air handlers located in the mechanical room.

Space Cooling System

Roland Hall

There is no central air-conditioning in Roland Hall. A Dectron dehumidification unit (model# DB-150-203) controls humidity levels in the indoor pool area. Waste heat off this unit's condenser is used to heat the pool water. It has a capacity of 13,000 cfm.

Waesche Hall

Air-conditioning is provided by a Trane Centra Vac centrifugal chiller located in a separate mechanical room. Chilled water is distributed to the three air handlers in Waesche Hall. Additionally, the chiller supplies cooling to adjacent Smith and Dimick Halls. A separate chilled water loop is split off to these buildings.

Fuel Cell Location

A description of the recommended fuel cell location is presented for each of the two potential applications. For Roland Hall, the assumption is made that gas can be brought up to the south side of the building. For Waesche Hall, it is assumed that a gas line would be brought in from Deshon Street.

Roland Hall

The fuel cell should be located on the existing solar hot water storage tank cement pad (Figure 4). The pad measures approximately 15-ft wide x 38-ft long. The storage tank is not used and should be removed to make room for the fuel cell. The thermal piping side of the fuel cell should face the building. The cooling module can also sit on the existing pad. A gravel bed should extend out from the pad 3 to 6 ft to provide sufficient clearance for maintenance personnel to work.

The low grade thermal piping from the fuel cell to the DHW storage tanks would be approximately 90 ft. Piping for a high grade heat loop connection would be approximately 120 ft. Natural gas input fuel to the fuel cell should be tied into the main gas line running through the parking lot. The make-up water can be taken from inside the building (~35 ft). The electrical run will be approximately 250 ft over to the electrical room from the fuel cell. The cooling module piping run is about 20 ft.

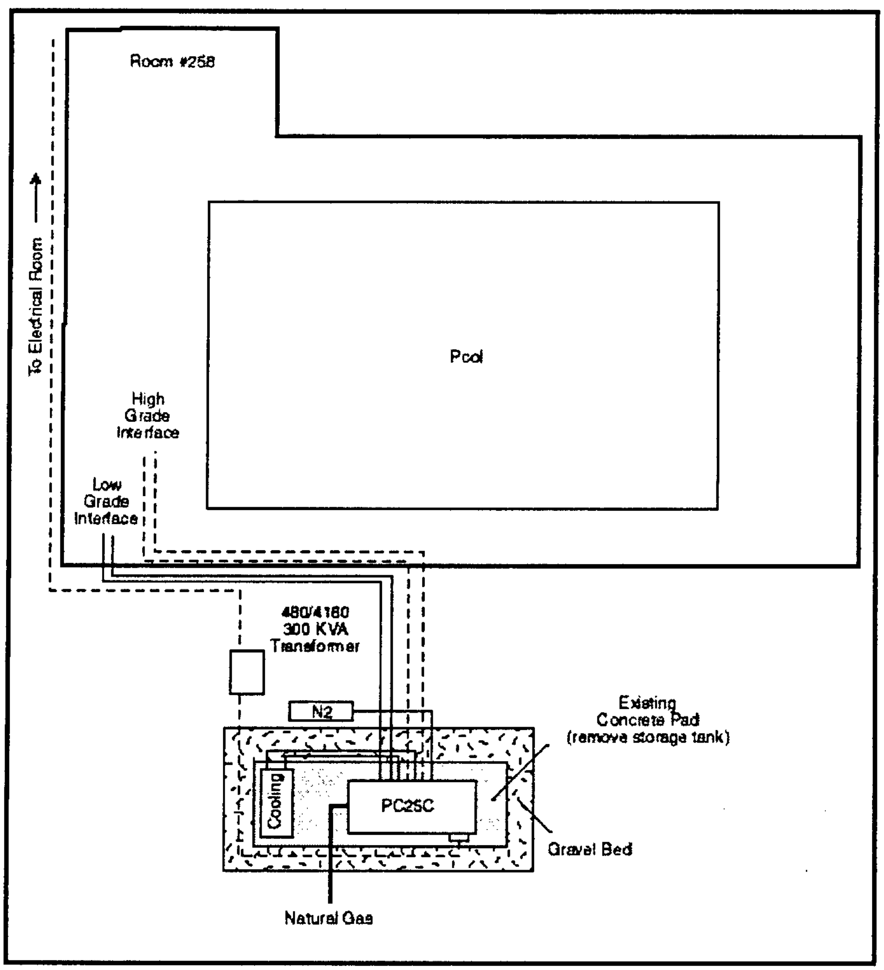

Figure 4. Roland Hall fuel cell location and interfaces.

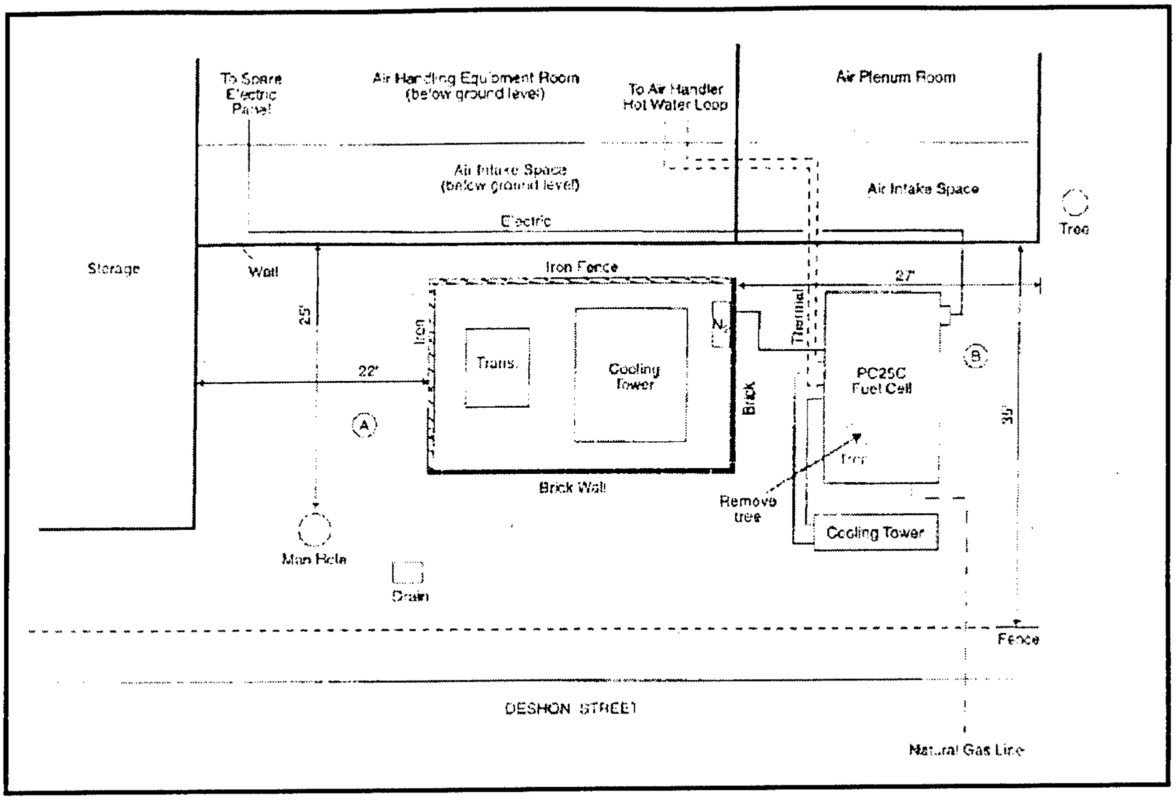

Figure 5. Waesche Hall fuel cell location and interfaces.

Waesche Hall

There are two potential locations for the fuel cell (Figure 5). Location A is large enough to accommodate the fuel cell; however it is quite tight. Location B is recommended because it does not extend the thermal piping requirement much beyond that for Location A, and it affords more room to site the fuel cell.

The thermal piping from the fuel cell to the mechanical room will be approximately 50 ft. Natural gas should be brought in from Deshon Street (~30 ft). The make-up water for the fuel cell can be taken from inside the building (~50 ft). The electrical run will be approximately 80 ft over to the electrical room. The cooling module piping run is approximately 20 ft.

Fuel Cell Interfaces

Fuel cell interfaces are discussed separately for Roland Hall and Waesche Hall.

Roland Hall

Electrical Interface

There is a 208/4160 V, 750 kVA transformer located in Roland Hall inside electrical room #260, which is surrounded by mechanical room #259. There are currently no electric loads with the same voltage as the fuel cell's 480 V output. Since the electric load of Roland Hall is expected to be very low at night when the facility is closed, it is possible that the minimum demand of the facility could be less than the nominal 200 kW of the fuel cell. It is recommended that the fuel cell be interfaced with the high voltage distribution side of the electrical system (inside room #260). This will require the installation of a 480/4160 V, 300 kVA transformer that would take the 480 volts of the fuel cell output and step it up to 4160 volts for distribution on the Academy grid. Since Roland Hall is part of the main electric service for the entire Academy, no fuel cell power would reach the utility grid.

Thermal Interface

Roland Hall has two primary mechanical rooms. One mechanical room (room #258) contains the two 1400-gal domestic hot water (DHW) storage tanks, which are heated through in-tank steam heat exchangers. In room #258, thermal loads consist of DHW, laundry, space heating, and supplemental heat for the swimming pool. The other mechanical room (room #259) has a steam-to-hot-water heat exchanger where the hot water is used for space heating.

The two best options for heat recovery are the DHW load and the space heating load, both accessible in room #258. This mechanical room is located closer to the proposed fuel cell location, and thus will result in shorter piping runs than to room #259. A pool heating load at nearby Billard Hall was also considered during the site visit, but was eliminated from further consideration due to the length of the required thermal piping run.

Domestic Hot Water Heating Requirements

The DHW system has a recirculation loop to maintain hot water at all the fixtures. To interface the fuel cell to this system, the cold water makeup and the return from the recirculation loop would be pumped through the fuel cell and back to the storage tanks. It is assumed that the hot water from the fuel cell would enter the storage tanks at an available penetration fitting (i.e., one designed for a recirculation return). Currently, the recirculation return is introduced into tanks at the cold water makeup piping. The storage tanks are con-

trolled to 140 °F, and the average temperature of the cold water make-up is estimated to be 60 °F.

The inputs and assumptions listed in Table 1 were used to estimate the contribution of the fuel cell supplemental heating for the DHW system. This schedule is typical of each week of the year, including the summer months when school is not in session.

Table 1. Roland Hall hours of operation.

Day of Week	Hours of Operation	Hours/Day
Mon-Fri	0600 – 2130	11.5
Sat	1200 – 2130	9.5
Sun	1200 – 2000	8.0
Average Day		10.7

Table 2 lists occupancy numbers for the typical usage of the facility during the academic year. During the summer, the weekday usage drops to approximately 500 people and the weekend usage is approximately 100 people.

Table 2. Roland Hall estimated occupancy.

Weekday	Hours
Cadets	850
Other CG Schools	150
Other Schools & Colleges	75
Faculty & Staff	75
Regular Outside Users	50
Total	1200
Weekend	500
Average Day	1000

Using hot water demand reference data from the 1991 ASHRAE Applications Handbook (Chapter 44 – Service Water Heating), the closest description to Roland Hall is a dormitory, which consists of showers, lavatories, service sinks and washing machines. On average, hot water demand is estimated to be 13.1 gal/student/day for men and 12.3 gal/student/day for women. Assuming that the mix of students is 75 percent male and 25 percent female, an average daily rate of hot water consumption of 12.9 gal/student/day was used:

$$12.9 \text{ gal/student/day} = ((75\% \times 13.1 \text{ gal/student/day}) + 25\% \times 12.3 \text{ gal/student/day}))/100\%$$

Table 3. Roland Hall DHW heating rates.

Period	Day Type	Occupants	Hours of Operation	Average Rate of Heating Required (kBtu/hr)
Oct–Apr	Weekday	1,200	11.5	897
Oct–Apr	Saturday	500	9.5	452
Oct–Apr	Sunday	500	8.0	537
Jun–Aug	Weekday	500	11.5	374
Jun–Aug	Saturday	100	9.5	90
Jun–Aug	Sunday	100	8.0	107

Table 3 lists the average rate of DHW heating required by time period to heat the make-up water (12.9 gal/occupant/day) and maintain the storage tank temperature at 140 °F during the hours of facility operation. An example calculation of the average rate of heating on a weekday during the months of October through April is:

$$897{,}030\,\text{Btu/hr} = \frac{1200\,\text{occupants/day} \times 12.9\,\text{gal/occ/day} \times 8.33\,\text{lb.gal} \times 1\,\text{Btu/lb}\,^{\circ}\text{F} \times (140-60)^{\circ}\text{F}}{11.5\,\text{hr/day}}$$

In addition to the make-up water heating requirement, heating is required to compensate for losses due to the DHW recirculation loop. The recirculation losses are estimated as follows:

Flow Rate:	30 gpm
Supply Temperature:	140 °F
Return Temperature (winter):	120 °F
Return Temperature (summer):	125 °F

Winter: 299,880 Btu/hr = 30 gal/min x 8.33 lb/gal x 1.0 Btu/lb °F x (140 – 120) °F x 60 min/hr

Summer: 224,910 Btu/hr = 30 gal/min x 8.33 lb/gal x 1.0 Btu/lb°F x (140 – 125) °F x 60 min/hr

Note that the only difference between the winter and summer recirculation losses is the estimated return temperature.

Table 4 lists the average hourly demand for DHW during facility hours of operation (the combination of DHW demand and recirculation losses).

Figure 6 shows the demand profile for the DHW system on a weekday when school is in session.

Table 4. Roland Hall average DHW demand.

Period	Day Type	Cold Water Makeup (kBtu/hr)	Recirculation Loop (kBtu/hr)	Total (kBtu/hr)
Oct–Apr	Weekday	895	300	1195
Oct–Apr	Saturday	450	300	750
Oct–Apr	Sunday	540	300	840
Jun–Aug	Weekday	375	225	600
Jun–Aug	Saturday	90	225	315
Jun–Aug	Sunday	110	225	335

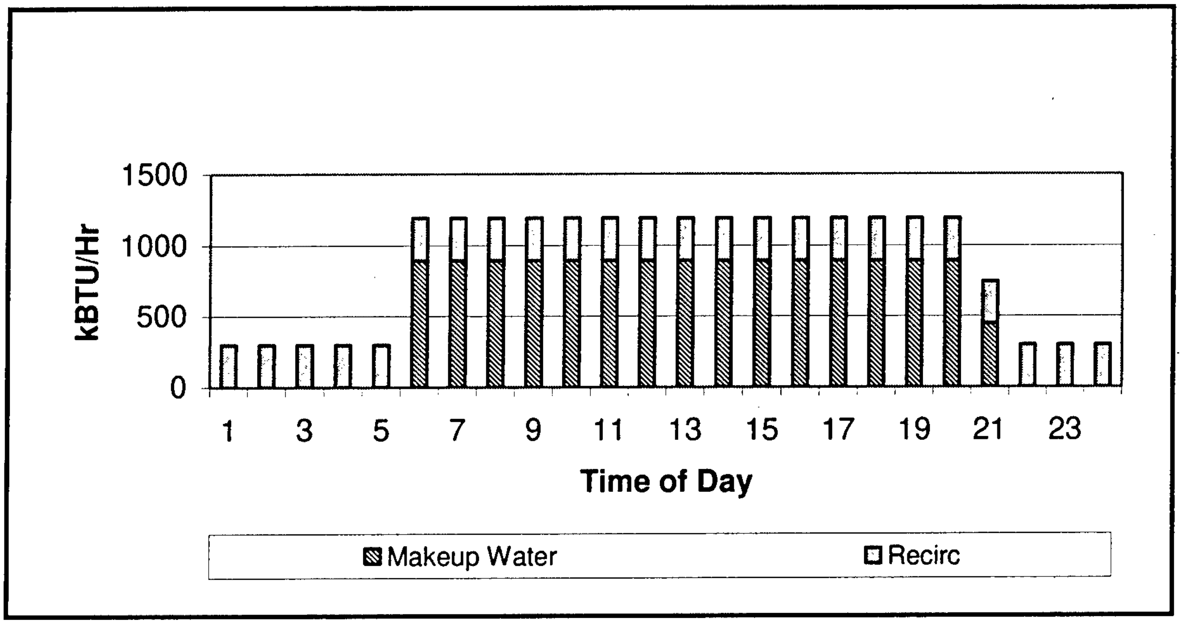

Figure 6. Roland Hall DHW average hourly demand—school weekday.

The maximum output capacity of the fuel cell is 700 kBtu/hr. When the demand exceeds this capacity (6:00 a.m. – 9:30 p.m.), all of the fuel cell thermal output will be used to heat the DHW. In the evening hours when the facility is closed, the average demand due to the recirculation loop losses is approximately 40 percent of the fuel cell capacity. In this case, 40 percent of the fuel cell thermal output will be used to heat the DHW and the other 60 percent will be rejected through the fuel cell's air cooling module. With the constant fuel cell thermal output of 700 Btu/hr and the above DHW load profile, the fuel cell will be capable of supplying 13,600 kBtu of the DHW heat required during the day. This represents a thermal use of the fuel cell heat of 81.0 percent.

This analysis was conducted for all six day types. Table 5 lists the results. Note that weekdays when school is in session have the highest thermal use and Saturdays during the summer have the lowest thermal use.

Table 5. Roland Hall fuel cell utilization—daily DHW

Period	Day Type	Daily DHW Demand (kBtu)	Daily Fuel Cell Output (kBtu)	Daily Fuel Cell Contribution (kBtu)	Fuel Cell Thermal Utilization (%)
Oct–Apr	Weekday	17,493	16,800	13,600	81.0%
Oct–Apr	Saturday	11,475	16,800	11,025	65.6%
Oct–Apr	Sunday	11,520	16,800	10,400	61.9%
Jun–Aug	Weekday	9,713	16,800	11,213	66.7%
Jun–Aug	Saturday	6,255	16,800	6,255	37.2%
Jun–Aug	Sunday	6,280	16,800	6,280	37.4%

Table 6. Roland Hall DHW thermal utilization.

Month	Operation Days/Month	Fuel Cell Output kBtu	Fuel Cell Contribution (kBtu)	Fuel Cell Thermal Utilization
January	31	520,800.0	395,925.0	76.0%
February	28	470,400.0	357,700.0	76.0%
March	31	520,800.0	398,500.0	76.5%
April	30	504,000.0	384,900.0	76.4%
May	31	520,800.0	340,857.5	65.4%
June	30	504,000.0	296,815.0	58.9%
July	31	520,800.0	303,070.0	58.2%
August	31	520,800.0	308,027.5	59.1%
September	30	504,000.0	351,976.3	69.8%
October	31	520,800.0	395,925.0	76.0%
November	30	504,000.0	384,900.0	76.4%
December	31	520,800.0	398,500.0	76.5%
Total	365	6,132,000.0	4,317,096.3	70.4%

The daily information in Table 5 has been used to determine the monthly and annual estimates of the fuel cell thermal output that can be used by the DHW system. The DHW system was estimated to use 70.4 percent of the thermal output of the fuel cell on an annual basis (Table 6).

Fuel Cell Thermal Interface to DHW

Figure 7 shows the thermal interface design for the DHW load at Roland Hall. To maximize fuel cell thermal use, priority should be given to the fuel cell thermal output for heating the storage tank. This can be accomplished using a control strategy that keeps the storage tank set point temperature at 140 °F, but lowers the steam loop control set point temperature. Thus, as long as the fuel cell can keep up with the heating requirement, the steam will not come on. In the case where the DHW demand significantly exceeds the fuel cell capacity (i.e., the storage tank temperature falls below 130 °F), the steam will come on and heat the tanks to 140 °F.

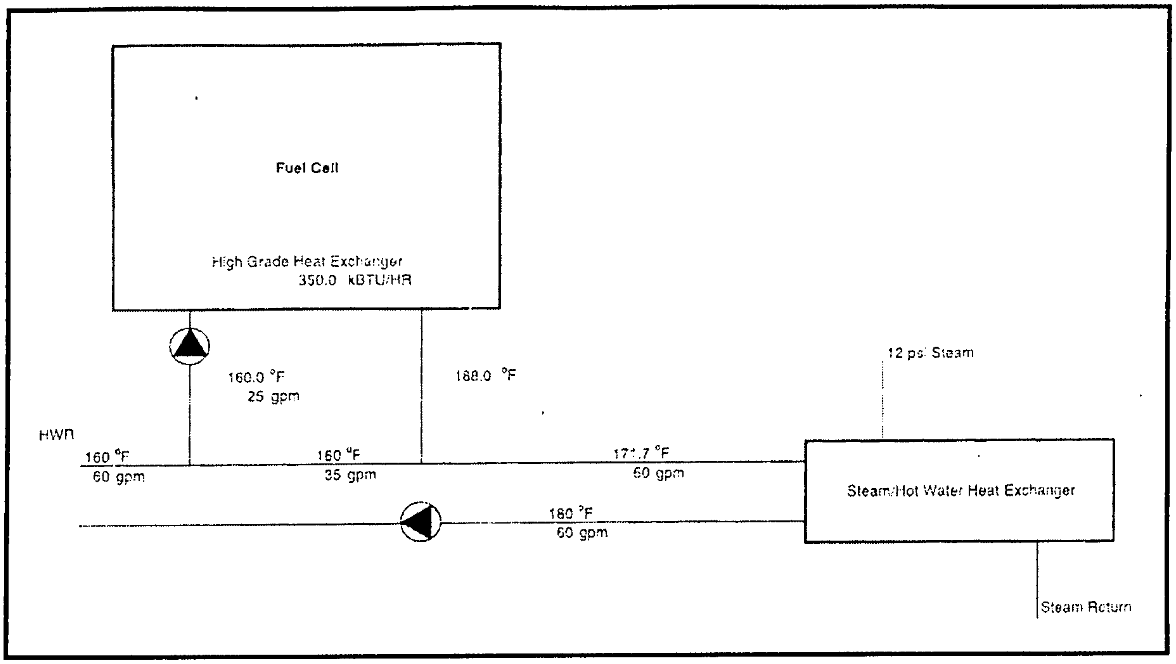

Figure 7. Building 3159 space heating loop heating recovery.

The fuel cell thermal interface to the DHW system will involve pumping 25 gal/min of water from the cold water make-up and recirculation return loop through the fuel cell to be heated. The resulting temperatures of water leaving the fuel cell and delivered to the storage tanks is presented for both the maximum load condition and the minimum load condition.

Maximum Load Condition:

Occurrence: October–April, Weekday between 6:00 a.m. and 9:30 p.m.

Average Load: 1195,000 Btu/hr (see Table 4)

Cold Water Make-up: 22.4 gpm at 60 °F

$$22.4\,\text{gpm} = \frac{1200\,\text{students/day} \times 12.9\,\text{gal/student}}{11.5\,\text{hr/day} \times 60\,\text{min/hr}}$$

Recirculation Water: 30 gpm at 120 °F

Fuel Cell Entering: 25 gpm at 94.3 °F

$$94.3\ ^{\circ}\text{F} = \frac{((22.4\,\text{gpm} \times 60\ ^{\circ}\text{F}) + (30\,\text{gpm} \times 120\ ^{\circ}\text{F}))}{22.4\,\text{gpm} + 30\,\text{gpm}}$$

Fuel Cell Contribution: 700,000 Btu/hr (maximum fuel cell output)

Fuel Cell Leaving Temp: 150 °F =

$$150\ ^{\circ}F = 94.3\ ^{\circ}F + \frac{700{,}000\,\text{Btu/hr}}{25\,\text{gpm} + 8.33\,\text{lb/gal} \times 1\,\text{Btu/lb}\ ^{\circ}F \times 60\ \text{min/hr}}$$

Minimum Load Condition:

Occurrence:	June – August, Weekday between 9:30 p.m. and 6:00 a.m.
Average Load:	225,000 Btu/hr (see Table 4)
Cold Water Make-up:	0 gpm
Recirculation Water:	30 gpm at 125 °F
Fuel Cell Entering:	25 gpm at 125 °F
Fuel Cell Contribution:	225,000 Btu/hr
Fuel Cell Leaving Temp:	143 °F

$$143\ ^{\circ}F = 125\ ^{\circ}F + \frac{225{,}000\,\text{Btu/hr}}{25\,\text{gpm} + 8.33\,\text{lb/gal} \times 1\,\text{Btu/lb}\ ^{\circ}F \times 60\ \text{min/hr}}$$

Space Heating Requirements

The option for using fuel cell heat recovery for building space heating was also evaluated. Due to the high temperatures required for these loads, the fuel cell would need to be purchased with the ONSI high grade heat exchanger option. To reduce interface piping runs, the space heating hot water loop accessible in mechanical room #258 was evaluated. Major loads for this application are:

Handball Court (S-2.21):	756.6 Btu/hr
Lockers (S-2.22):	185.0 Btu/hr
Pool Equipment (RH 23A/B):	116.7 Btu/hr
Lockers (S-2.24):	257.5 Btu/hr
Total	1315.8 Btu/hr

The design heating load is approximately four times the output capacity of the high grade heat exchanger option of 350,000 Btu/hr. It is assumed for this analysis that during operation of the facility, the minimum load would be at least 350,000 Btu/hr during the heating demand months (October – April). To estimate the annual potential fuel cell heat recovery for preheating the space heating return water at the steam heat exchanger, historical temperature bin data was used. The bin data was obtained from a software package developed by the Gas Research Institute (GRI) called "BinMaker™: The Weather Summary Tool." BinMaker™ data is based on TMY-2 data gathered by the National Renewable Energy Laboratory in Golden, CO. Table 7 lists the monthly hours of heating required for the building, based on outdoor dry bulb temperature.

Table 7. Roland Hall heating hours by month

Month	Hours of Heating	Average Outdoor Dry Bulb Temp. (°F)
January	739	23.06
February	664	28.70
March	632	32.85
April	201	40.45
May	45	40.64
June	0	N/A
July	0	N/A
August	0	N/A
September	38	38.95
October	200	39.66
November	466	35.32
December	693	27.47
Annual	3678	30.38

The monthly space heating requirement for the heat exchangers in room #258 was estimated based on the hours of heating from the above table and the design heating capacity of the heating coils. The average rate of heating is based on an equipment sizing criteria of design heat loss plus 30 percent and an operational diversity factor of 75 percent. The monthly fuel cell output is based on a high grade heat exchanger capacity of 350,000 Btu/hr during each hour of fuel cell operation. The monthly fuel cell contribution is estimated to be 350,000 Btu/hr for each hour of heating required. The data listed in Table 8 show that heat recovery from the fuel cell through a high grade heat exchanger for space heating alone will result in a fuel cell thermal use of 21.0 percent.

Figure 8 shows the fuel cell interface for preheating the space heating hot water. Heating loads for each coil were taken from the equipment schedule provided on the renovation plans, page M.7.2 The hot water-side has 155 gpm, 190 °F entering water temperature and a 210 °F leaving water temperature. The ONSI literature indicates that the high grade heat exchanger is capable of providing 350,000 Btu/hr with an inlet temperature of 190 °F. The fuel cell interface would be made on the return water piping of the hot water loop. A 25 gpm pump would pull 190 °F water from the loop and pass it through the fuel cell. The fuel cell, with a maximum high grade heating capacity of 350,000 Btu/hr, would then heat the water up to 218 °F. The 218 °F water would then be introduced back into the return water loop where the mixed temperature entering the steam to hot water heat exchanger would be 194.5 °F:

$$194.5\ °F = ((25\ gpm \times 218\ °F) + (130\ gpm \times 190\ °F))\ /\ 155\ gpm$$

$$218\ °F = 190\ °F + \frac{350{,}000\ Btu/hr}{25\ gpm + 8.33\ lb/gal \times 1\ Btu/lb\ °F \times 60\ min/hr}$$

Table 8. Thermal recovery for space heating loop.

Month	Operation (hrs/mo)	Monthly Space Heating Demand (kBtu)	Monthly Fuel Cell Output (kBtu)	Monthly Fuel Cell Contribution (kBtu)	Fuel Cell Thermal Utilization (%)
January	739	510,497.5	520,800.0	258,650.0	49.7%
February	664	458,687.9	470,400.0	232,400.0	49.4%
March	632	436,582.4	520,800.0	221,200.0	42.5%
April	201	138,849.8	504,000.0	70,350.0	14.0%
May	45	31,085.8	520,800.0	15,750.0	3.0%
June	0	0.0	504,000.0	0.0	0.0%
July	0	0.0	520,800.0	0.0	0.0%
August	0	0.0	520,800.0	0.0	0.0%
September	38	26,250.2	504,000.0	13,300.0	2.6%
October	200	138,159.0	520,800.0	70,000.0	13.4%
November	466	321,910.5	504,000.0	163,100.0	32.4%
December	693	478,720.9	520,800.0	242,550.0	46.6%
Total		2,540,744.0	6,132,000.0	1,287,300.0	21.0%

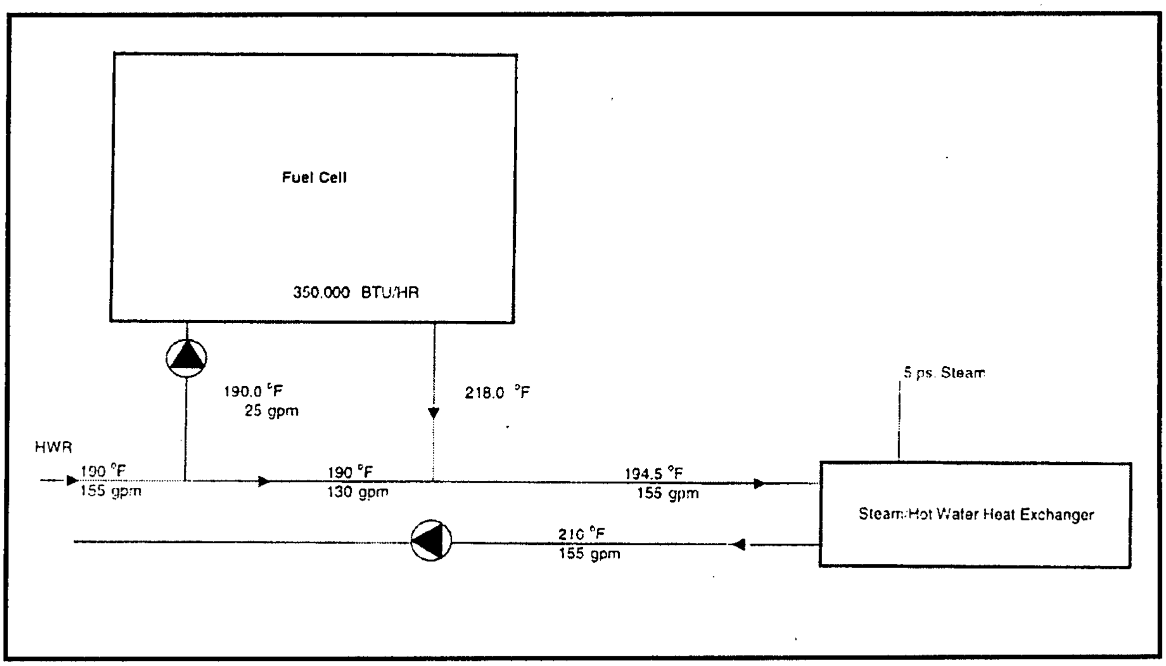

Figure 8. Roland Hall space heating loop heat recovery.

Fuel Heat Recovery for both DHW and Space Heating

The following analysis is presented to estimate the annual fuel cell thermal use for the application where the fuel is interfaced with both the DHW and space heating loads. The fuel cell would be configured such that the high grade heat exchanger would be interfaced to the space heating load and the low grade heat exchanger would be interfaced to the DHW load. Since the high grade heat exchanger has priority over the low grade heat exchanger (i.e., high grade heat removed first), the contribution of the fuel cell to the space heating load will be the same as that listed in Table 8.

When space heating is required by the building, the average load always exceeds the capacity of the fuel cell's high grade heat exchanger of 350,000 Btu/hr. As a result, the maximum rate of heat recovery from the fuel cell for the DHW load during times of space heating is 350,000 Btu/hr. It also is assumed that, during the time periods when there is no demand for space heating by the building, the rate of heat recovery for the DHW is equal to the average rate of heat recovery based on the data in Table 4. The resulting fuel cell heat recovery for both DHW and space heating is estimated to have a fuel cell thermal use of 81.0 percent. Table 9 lists the monthly values for this configuration.

The combined DHW and space heating approach is a desirable approach for this application since the DHW load profile could be very spiked. During times of low space heating demand, the fuel cell can provide heat to the DHW load. Note that, under fuel cell operation, the thermal loads associated with the high grade heat exchanger have a higher priority than the loads from the normal heat recovery heat exchanger since the two heat exchangers are piped in series within the fuel cell.

Natural Gas Interface

One issue with placing the fuel cell at Roland Hall is the availability of natural gas for the fuel cell. The nearest gas line is approximately 200 yd away. The cost of extending a gas line to Roland Hall was expected to be high due to difficulty in trenching the hard and rocky ground. A 2-in. natural gas line will need to be run from the nearest gas pipeline to the location of the fuel cell. The local gas utility company has evaluated the work required to provide a gas line to the proposed fuel cell location and has indicated that it would provide the required new piping at no cost to the Academy.

Table 9. Fuel cell thermal utilization for space heating.

Month	Monthly Fuel Cell Contribution to Space Heating (kBtu)	Monthly Fuel Cell Contribution to DHW (kBtu)	Total Monthly Fuel Cell Contribution (kBtu)	Monthly Fuel Cell Output (kBtu)	Fuel Cell Thermal Utilization (%)
January	258,650.0	224,360.8	483,010.8	520,800.0	92.7%
February	232,400.0	203,458.3	435,858.3	470,400.0	92.7%
March	221,200.0	249,589.2	470,789.2	520,800.0	90.4%
April	70,350.0	337,748.8	408,098.8	504,000.0	81.0%
May	15,750.0	333,741.1	349,491.1	520,800.0	67.1%
June	0.0	350,815.0	350,815.0	504,000.0	69.6%
July	0.0	358,870.0	358,870.0	520,800.0	68.9%
August	0.0	363,827.5	363,827.5	520,800.0	69.9%
September	13,300.0	395,949.7	409,249.7	504,000.0	81.2%
October	70,000.0	349,493.5	419,493.5	520,800.0	80.5%
November	163,100.0	275,584.2	438,684.2	504,000.0	87.0%
December	242,550.0	235,216.5	477,766.5	520,800.0	91.7%
Total	1,287,300.0	3,678,654.7	4,965,954.7	6,132,000.0	81.0%

Waesche Hall

Electrical Interface

There is a 480/4160 Volt, 1500 kVA transformer located outdoors on the north side of the building (between the building and Deshon Street). Waesche Hall is one of the few buildings at the Academy that is metered and billed separately by the electric utility company. The monthly peak demand for Waesche Hall ranges from 294 kW to 408 kW. Data provided by CL&P shows that the minimum demand for the building is less than the nominal 200 kW output from the fuel cell. To operate the fuel cell at this location, there are three options:

1. Consolidate the electrical load with the adjacent Smith Hall
2. Negotiate a sell-back option with the electric utility
3. Provide load control for the fuel cell to load follow when the demand is less then 200 kW.

If Option 3 above were implemented, the fuel cell capacity factor would be less than 65 percent. Option 2 is possible, but likely would result in a low price for electricity sold to the utility. The desirable option is to consolidate the loads for Waesche and Smith Halls. This can be done either physically or by requesting that CL&P combine the two existing bills and install a backwards meter, which would then be credited for the combined bills. CL&P has stated its willingness to work with the Academy to help bring this project about.

The building load data for Waesche and Smith Halls shows that the combined loads fall below 200 kW only about 1.5 percent of the time. Approximately 4.3 percent of the hours have combined loads of 201 to 240 kW (Table 10). Based on these data, the fuel cell electrical output would need to be reduced below its 200 kW capacity no more than 6 percent of the time.

Table 10. Combined electrical loads for Waesche and Smith Halls

Combined Loads	0 – 200 kW	201 – 240 kW	241 kW +	Totals
Hours	153	406	8,921	9,480
% of Data	1.6%	4.3%	94.1%	100%

The fuel cell should be interfaced electrically in the Waesche Hall electrical room using an available spare electrical panel. The fuel cell 480 V power would then be used at Waesche Hall. When this load falls below 200 kW, the additional fuel cell output would then be fed through the panel back to the 480/4160 V transformer for export to Smith Hall or the grid, depending on the agreement reached with CL&P.

Thermal Interface

Waesche Hall does not have hot water loads large enough to use the thermal output of the fuel cell. Space heating at Waesche Hall is achieved through an electric space heating system. The fuel cell thermal output could be used to offset the cost of electric heating by preheating the air into the existing air handlers (AC-1, AC-2, and AC-3), which are located in the air handling equipment room on the lower level of the building. The preheated air would offset some of the energy required to operate the electric reheat coils at the distributed VAV boxes. Figure 9 shows the existing air distribution system configuration.

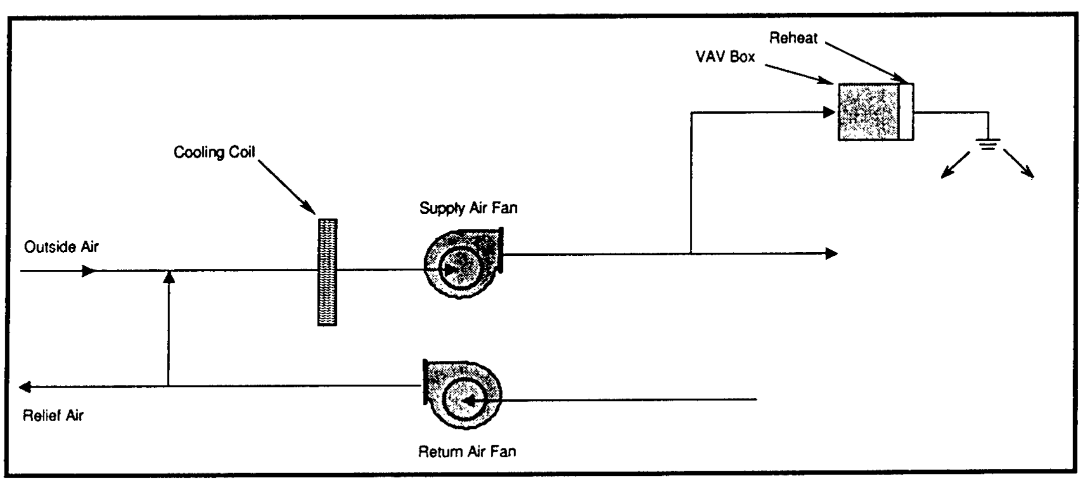

Figure 9. Waesche Hall air handler.

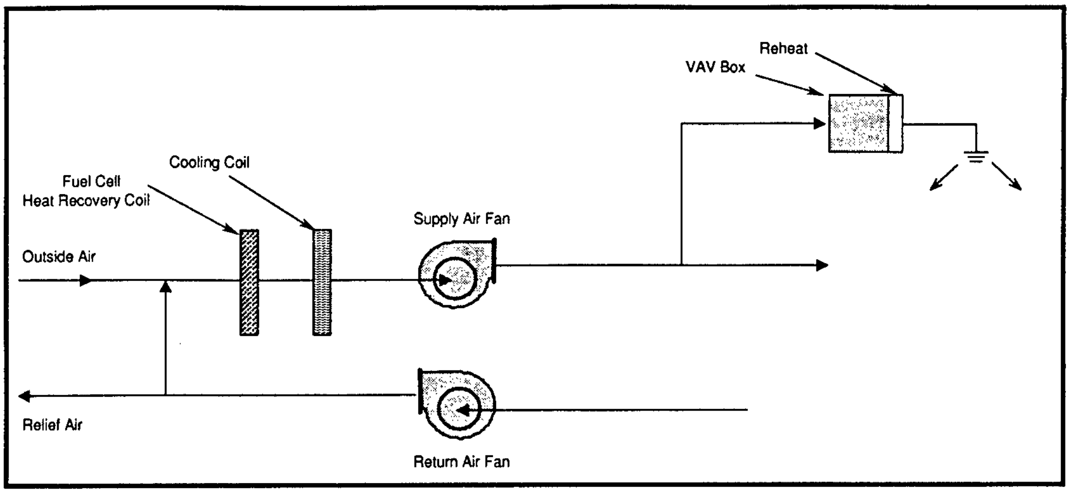

Figure 10. Waesche Hall air handler with fuel cell heat recovery coil.

A hot water-to-air heat exchanger would be installed in an air handling unit (Figure 10) to integrate the fuel cell thermal output for preheating the air stream. This preheating approach is quite common on VAV systems. However, before proceeding with such an approach, the air distribution system and operation needs to be examined in more detail to ensure that sending warm air to the VAV boxes will achieve the required comfort levels. Issues to examine include:

- adjusting air flow/temperature set points during the heating mode
- ensuring that interior zones do not get too warm.

The potential for heat recovery from the fuel cell to preheat the air for space heating is evaluated below. First, the design heating load for each air handler was estimated. The number of VAV boxes, air flow rates and total heater kW data were obtained from the mechanical plans provided by the Academy. Total heating capacity was based on a 90 percent efficiency.

Total Heating Capacity = Heater kW x 3.413 kWh/kWh x 90% efficiency

The design heating load was estimated to be 70 percent of the installed total heating capacity in the building. The total design heating load for the entire building is approximately 885,900 Btu/hr (Table 11).

Table 11. Total design space heating load for Waesche Hall.

Building Zone	Number of VAV Boxes	Total Heating (CFM)	Total Heater (kW)	Total Heating Capacity (kBtu/hr)	Design Heating Load (kBtu/hr)
Lower Level	24	16,353	156	479.2	335.4
Entrance Level	16	15,628	151	463.8	324.7
Upper Level	10	17,733	105	322.5	225.8
Total	50	49,714	412	1,265.5	885.9

Historical temperature bin data was used to estimate the annual potential for fuel cell heat recovery. The bin data was obtained from "BinMaker™: The Weather Summary Tool." The monthly hours of heating required for the building were based on the data table presented previously for Roland Hall.

To use the fuel cell's full 700,000 Btu/hr thermal output capability, the fuel cell should be interfaced with all three air handling units. A custom water-to-air heat exchanger should be installed in each air handler to preheat the air delivered to individual VAV boxes. To interface to the fuel cell thermally with the existing space heating system, a circulating hot water loop, fed by the fuel cell, should be interfaced with the three new heat exchangers located in the air handlers. Figure 11 shows the thermal interface. A 75 gpm hot water loop would feed the hot water heat exchangers in a parallel configuration. The flow through each individual heat exchanger is estimated to be 25 gpm. A separate loop, controlled by a mixing valve, would divert 25 gpm through the fuel cell heat exchanger to extract up to 700,000 Btu/hr. The flow through the fuel cell would be controlled by a mixed delivery temperature of 120 °F in the 75 gpm hot water loop. The return temperature will vary depending on the heat requirements of the building.

The quantity of preheating to be provided by the fuel cell was estimated using the assumption that the fuel cell will heat the outside make-up air to 70 °F. The quantity of make-up air used to estimate the heating requirement was obtained from "As-Built" drawings provided by the Academy. The total make-up air is 10,050 CFM. Table 12 lists the estimated fuel cell contribution based on the average monthly temperatures and hours of heating from Table 11.

The fuel cell is capable of putting out a total of 6,132,000 Btu/yr [(700 Btu/hr x 24 hr/day x 365 day/yr)]. Thus, the projected thermal use from the fuel cell would be 26 percent (1,605,067/6,132,000).

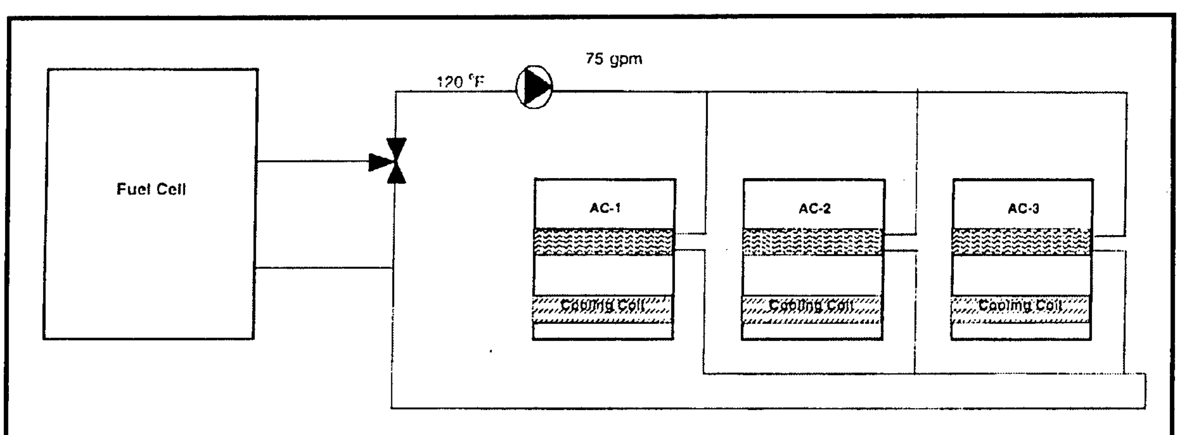

Figure 11. Waesche Hall space heating loop fuel cell interface.

Table 12. Fuel cell displaced space heating energy

Month	Hours of Heating	Average Outdoor Dry Bulb Temp. (°F)	Outdoor Air Heating Load (kBtu/hr)	Outdoor Air Heating Load (kBtu)	kWh
January	739	23.06	513.7	379,652	123,597
February	664	28.70	455.8	302,643	98,526
March	632	32.85	409.9	259,077	84,343
April	201	40.45	326.1	65,536	21,336
May	45	40.64	323.9	14,577	4,746
June	0	—	—	—	—
July	0	—	—	—	—
August	0	—	—	—	—
September	38	38.95	342.7	13,021	4,239
October	200	39.66	334.8	66,960	21,799
November	466	35.32	382.7	178,346	58,061
December	693	27.47	469.3	325,254	105,887
Total	3,678	30.38		1,605,067	522,534

Natural Gas Interface

A 4-in. natural gas line runs down Deshon Street. The distance from the proposed fuel cell location to the gas line in the street is approximately 35 ft. A new 2-in. gas line will need to be interfaced to the existing 4-in. line and brought to the fuel cell location. Yankee Gas inspected the gas line on Deshon Street. It is a 4-in. low pressure iron pipe (6-in. wc). They would upgrade the main gas line to 2 psi pressure and bring a gas line into the fuel cell at no additional cost to the Academy.

3 Economic Analysis

The Academy purchases electricity from Connecticut Light & Power (CL&P). They are billed under five separate billings meters, which include the main base, Waesche Hall, Smith Hall, the Child Development Center, and the Rowing Center. The main meter is billed under "Rate 58 – Large Time-of-Day (TOD)," which has both an on-peak and off-peak period. The on-peak period runs between the hours of 7 a.m. and 11 p.m., Monday through Friday. The off-peak period are all other hours including weekends and holidays.

Table 13 lists the electric bills from September 1997 through July 1998 for the main base. Monthly on-peak demand at the Academy (main meter) ranged from 1764 to 2101 kW between September 1997 and July 1998. Table 14 lists energy bill data from September 1997 through July 1998 for Waesche Hall, which is metered under "Rate 56 – Intermediate TOD." The monthly on-peak demand at the Waesche Hall ranged from 294 to 408 kW between September 1997 and July 1998.

Natural gas is purchased from Yankee Gas. As mentioned previously, there is currently no gas service at either Roland Hall or Waesche Halls. Discussions with Yankee Gas about the potential installation of gas service were initiated. After investigating and evaluating the location of gas lines, Yankee Gas concluded that it would install a gas line up to either fuel cell location at no charge to the Academy. The gas rate schedule would be Rate 27:

Customer Service Charge:	\$350/mo.
Demand Charge:	\$1.25/Ccf/mo.
Commodity Charge:	
April-October:	\$0.2833/Ccf
November-March:	\$0.5255/Ccf

The Academy signed an agreement with CL&P to participate in their Energy Action Program (EAP), which provides incentives for certain energy efficiency measures. One stipulation of this agreement is that the Academy agrees to purchase all of its electricity from CL&P. The ability to install a fuel cell will need to be addressed with CL&P to ensure that the Academy does not compromise the incentives that it already has received. The worst case scenario is that the Academy would have to pay back, on a pro-rated basis, a portion of the rebates that it already has received (e.g., the last year of a 3-year agreement, etc.).

Table 13. U.S. Coast Guard main base electric bill summary (Rate 58).

Bill Start Date	Bill End Date	On-Peak (kW)	Off-Peak (kW)	Energy (kWh)	Total Cost
08-Sep-97	29-Sep-97	1,825	1,576	592,000	$51,050
29-Sep-97	29-Oct-98	1,792	1,475	849,600	$73,030
29-Oct-98	01-Dec-98	1,764	1,360	916,800	$76,497
01-Dec-98	31-Dec-98	*Data not available*			
31-Dec-98	30-Jan-98	1,880	1,504	910,400	$76,561
30-Jan-98	02-Mar-98	1,947	1,537	945,600	$78,532
02-Mar-98	30-Apr-98	*Data not available*			
30-Apr-98	01-Jun-08	1,884	1,417	809,600	$70,053
01-Jun-08	31-Jul-98	*Data not available*			
31-Jul-98	31-Aug-98	2,101	1,834	958,400	$79,242
Totals:				5,982,400	$504,965

Table 14. U.S. Coast Guard Waesche Hall electric bill summary (Rate 56).

Bill Start Date	Bill End Date	On-Peak (kW)	Off-Peak (kW)	Energy (kWh)	Total Cost
08-Sep-97	29-Sep-97	369	341	134,400	$11,315
29-Sep-97	29-Oct-98	354	362	153,600	$13,731
29-Oct-98	01-Dec-98	294	263	155,520	$13,482
01-Dec-98	31-Dec-98	*Data* not available			
31-Dec-98	30-Jan-98	335	321	156,480	$13,685
30-Jan-98	2-Mar-98	325	341	164,160	$13,998
02-Mar-98	30-Apr-98	Data not *available*			
30-Apr-98	01-Jun-08	385	359	171,840	$14,963
01-Jun-08	31-Jul-98	*Data not available*			
31-Jul-98	31-Aug-98	408	394	230,400	$18,204
Totals:				1,166,400	$99,377

Roland Hall

Roland Hall electric savings are based on Rate 58, which applies to the main base electric meter. Displaced electricity savings from the fuel cell were estimated based on it operating 90 percent of the year (1576,800 kWh). This is a conservative estimate in that it takes into consideration downtime for scheduled maintenance as well as unscheduled downtime. The fuel cell is capable of operating at greater than 90 percent availability. Note that, with an 11-month ratchet on the distribution demand portion, any distribution demand savings from the fuel cell would not be realized until after the first 11 successive months of peak demand reduction. Table 15 lists electricity savings from the fuel cell based on a 90 percent availability and 100 percent credit for demand savings.

Table 15. Fuel cell electrical savings—Roland Hall.

Prod./Trans. kW	2,400	$6.02	$14,448
Distribution kW	2,400	$4.12	$9,888
On-peak kWh	750,557	$0.06683	$50,160
Off-peak kWh	826,243	$0.04772	$39,428
Total			$113,924

Thermal savings from the fuel cell would come from displacing fuel oil used at the heating plant. The cost of fuel oil at the Academy is approximately 47 cents/gal from May-September, and 50 cents/gal the remaining months of the year. Using an average annual rate of 48 cents/gal at 151,000 Btu/gal, this equates to approximately $3.18/MMBtu. For purposes of calculating thermal energy savings, a seasonal boiler efficiency of 75 percent was assumed. Table 16 lists the DHW thermal savings for Roland Hall.

Table 16. DHW thermal savings—Roland Hall.

Site Thermal Displaced	4,317,096 kBtu/yr
Seasonal Boiler Efficiency	75%
Displaced Fuel Oil	5,756,128 kBtu/yr
Average Fuel Oil Rate	$3.18/MMBtu
Fuel Cell Thermal Savings	$18,304

Yankee Gas has agreed to provide natural gas to the fuel cell under Rate 27. Since this would be a new service at Roland Hall, the total fuel cell cost would include the service charge. Table 17 lists the total annual cost. A demand requirement of 25 Ccf was assumed, which is the average between the initial 19 Ccf/hr at startup and the maximum projected flow rate of 30 Ccf as stack efficiency degrades.

Table 17. Input fuel costs.

Service Charge	$4,200 = $350 x12 mo/yr
Demand Charge	$375 = 25 Ccf x $1.25/Ccf x 12 mo/yr
Commodity Charge	$57,340 = 14,949 MMBtu/yr x $3.84/MMBtu*
Total Fuel Cost	$61,915 = $4,200 + $375 + $57,340
*$3.84 MMBtu = ((214/365 days/yr x $0.2833/Ccf) + (151/365 days/yr x $0.5255/Ccf)) x 10 Ccf/MMBtu	

The estimated net savings for the DHW/Recirculation loop is $70,313. Factoring in the 11-month ratchet on distribution demand, first year savings would be reduced by $9,064 (11 mo/12 mo * $9,888 distribution demand) to $61,249:

$70,313 = $113,924 + $18,304 – $61,915

$61,249 = $70,313 – $9,064

Table 18 lists data pertaining to this case and to several others, to show a range of potential savings scenarios. These scenarios include the addition of the space heating load, a 50 percent thermal use case and the impact of reduced electrical demand displacement (50 percent and zero demand savings). Adding a high grade heat exchanger for the space heating loop increases the net annual energy savings by ~$2,700.

The estimated savings discussed thus far do not factor in maintenance costs, stack replacement costs, cell stack degradation, or overall lifecycle costs. An analysis was performed to show the net present value (NPV) over the life of the fuel cell. NPV is the sum of future cash flows discounted at a given rate (generally a required rate of return). If NPV is positive, then the project is an acceptable investment. If NPV is negative, then the required rate of return has not been met and the project is not acceptable. Table 19 lists the lifecycle cost analysis input assumptions.

The fuel cell installation cost includes a new electric transformer. Since a pad already exists for the fuel cell at Roland Hall, it was assumed that the cost of the new transformer did not warrant an additional cost above $100,000. An additional $25,000 is added for the installation of a high grade heat exchanger to interface with the space heating loop. Maintenance costs of $18,000 are based on a commercial rate and represent approximately 1.1 cents/kWh. Stack replacement costs are based on ONSI's projection of one-third the cost of the projected commercial power plant cost of $1500/kW (i.e., $1500/kW * 200 kW * 1/3). A $200,000 fuel cell rebate is available through the Department of Energy (DOE) to pay for up to one-third of the fuel cell purchase price. In the model, it was assumed that the fuel cell stack would have a life of 60,000 hours (~ 7 years) and that stack efficiency would degrade based on operating hours.

The price of an ONSI PC25C fuel cell recently increased to $850,000. Three fuel cell cost scenarios were analyzed: $850,000, $650,000 (new price with rebate or old price without rebate), and $450,000 (old price with rebate). Table 20 lists 20-year IRR and NPV estimates for the three energy savings cases presented in Table 18 (full demand savings). Internal Rates of Return (IRRs) ranged from 1.4 percent to 12.6 percent, and NPVs ranged from $347,477 to –$542,611. Table 21 lists the lifecycle cost analysis for DHW/Recirc. at $650,000.

Table 18. Roland Hall fuel cell energy savings summary.

Case	ECF	TU	Displaced kWh	Displaced Fuel (MMBtu)	Electrical Savings	Thermal Savings	Nat. Gas Cost	Net Savings
Full Demand Savings								
DHW / Recirc.	90%	70%	1,576,800	5,756	$113,924	$18,304	$61,915	$70,313
DHW / Recirc. + Heating	90%	81%	1,576,800	6,618	$113,924	$21,045	$61,915	$73,054
50% Thermal Utilization	90%	50%	1,576,800	4,088	$113,924	$13,000	$61,915	$65,009
50% Demand Savings								
DHW / Recirc.	90%	70%	1,576,800	5,756	$101,756	$18,304	$61,915	$58,145
DHW / Recirc. + Heating	90%	81%	1,576,800	6,618	$101,756	$21,045	$61,915	$60,886
50% Thermal Utilization	90%	50%	1,576,800	4,088	$101,756	$13,000	$61,915	$52,841
Zero Demand Savings								
DHW / Recirc.	90%	70%	1,576,800	5,756	$89,588	$18,304	$61,915	$45,977
DHW / Recirc. + Heating	90%	81%	1,576,800	6,618	$89,588	$21,045	$61,915	$48,718
50% Thermal Utilization	90%	50%	1,576,800	4,088	$89,588	$13,000	$61,915	$40,673

Assumptions:

Electric Rate: $0.07225 /kWh (Average—See CL&P Rate 58)
Input Fuel Rate: $4.14 /MMBtu (Average—See Yankee Gas Rate 27)
Displaced Fuel Rate: $3.18 /MMBtu (151,000 Btu/gal @ 48 cents/gal annual avg.)
Fuel Cell Thermal Output: 700,000 Btu/hour
Fuel Cell Electrical Efficiency (HHV): 36%
Seasonal Boiler Efficiency: 75%
ECF = Fuel cell electric capacity factor
TU = Thermal utilization

Table 19. Lifecycle cost input assumptions—Roland Hall

Capital cost	$650,000
Installation cost	$100,000*
Maintenance cost	$18,000/yr
Stack replacement cost	$100,000
Fuel cell rebate	$200,000
Stack life	60,000 hours
Cycles per year	1
Escalation rates	3% per year
NPV discount rate	4%, 10%, 15%, 20%
*Add $25,000 for installation of high grade heat exchanger	

Table 20. Lifecycle cost summary results for Roland Hall.

Case	F.C. Cost	IRR	NPV @ 4%	NPV @ 10%	NPV @ 15%	NPV @20%
	$450k	12.6%	$324,313	$65,091	–$45,969	–$112,881
DHW	$650k	6.3%	$124,313	–$134,909	–$245,969	–$312,881
Recirc.	$850k	2.9%	–$75,687	–$334,909	–$445,969	–$512,881
DHW	$450k	12.5%	$347,477	$68,736	–$50,648	–$122,517
Recirc.	$650k	6.6%	$147,477	–$131,264	–$250,648	–$322,517
+ Heating	$850k	3.3%	–$52,523	–$331,264	–$450,648	–$522,517
50%	$450k	10.4%	$231,114	$9,662	–$85,291	–$142,611
Thermal	$650k	4.6%	$31,114	–$190,338	–$285,291	–$342,611
Utilization	$850k	1.4%	–$168,886	–$390,338	–$485,291	–$542,611

Table 21. Roland Hall (DHW/Recirc. Case) 20-year lifecycle analysis.

Fuel Cell Costs		Fuel Cell Performance		Operation		Financial	
Capital Cost ($/kW)	$3,250	Electrical Efficiency (HHV)	0.36	Equipment Life (Years)	20	Demand Savings ($/yr)	24,336
Installation Cost ($/kW)	$500	Overall Efficiency (HHV)	0.73	Capacity Factor	0.9	Energy Savings ($/yr)	89,588
Maintenance Cost ($/YR.)	$18,000	Cell Voltage (volts/cell)	0.7	Cycles per Year	1	Input Fuel Cost ($/yr)	61,915
Stack Replacement Cost ($/kW)	$500	Cycle Degradation (mV/cycle)	6	Displaced Boiler Efficiency	0.75	Thermal Savings ($/yr)	18,304
Fuel Cell Rebate ($/kW)	$1,000	Operating Degradation (mV/1000 hrs)	2	Thermal Utilization (MMBtu/yr)	4,317.1	Inflation	0.03
		Stack Life (Hours)	60,000			Fuel Escalation	0.03
		Fuel Cell Size (kW)	200			Electric Escalation	0.03
		Months of Demand Reduction:	12			NPV Discount Rate	0.10

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Intermediate Calculations																				
Hours																				
Operation Hours/Yr.	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884
Total Operation Hours	7,884	15,768	23,652	31,536	39,420	47,304	55,188	63,072	70,956	78,840	86,724	94,608	102,492	110,376	118,260	126,144	134,028	141,912	149,796	157,680
Total Stack Hours	7,884	15,768	23,652	31,536	39,420	47,304	55,188	3,072	10,956	18,840	26,724	34,608	42,492	50,376	58,260	6,144	14,028	21,912	29,796	37,680
Degradation (V)																				
Operating	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0031	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0061	0.0079	0.0079	0.0079	0.0079
Cycling	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060
Net Cell Volts	0.6861	0.6722	0.6583	0.6445	0.6306	0.6167	0.6028	0.6909	0.6770	0.6632	0.6493	0.6354	0.6215	0.6076	0.5937	0.6879	0.6740	0.6601	0.6462	0.6323
Operation Values																				
Electrical Eff (%)	35.3%	34.6%	33.9%	33.1%	32.4%	31.7%	31.0%	35.5%	34.8%	34.1%	33.4%	32.7%	32.0%	31.2%	30.5%	35.4%	34.7%	33.9%	33.2%	32.5%
Thermal Eff (%)	37.7%	38.4%	39.1%	39.9%	40.6%	41.3%	42.0%	37.5%	38.2%	38.9%	39.6%	40.3%	41.0%	41.8%	42.5%	37.6%	38.3%	39.1%	39.8%	40.5%
Demand Disp. (kW)	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Electric Output (MWh)	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8
Thermal Displ. (MMBtu)	4317.1	4317.1	4317.1	4317.1	4317.1	4317.1	4317.1	4317.1	4317.1	4317.1	4317.1	4317.1	4317.1	4317.1	4317.1	4317.1	4317.1	4317.1	4317.1	4317.1
Fuel Input (MMBtu)	15,251	15,566	15,895	16,237	16,595	16,968	17,359	15,145	15,456	15,779	16,117	16,469	16,837	17,222	17,624	15,213	15,526	15,853	16,193	16,549
Average Energy Rates																				
Demand Rate ($/kW):	10.14	10.44	10.76	11.08	11.41	11.76	12.11	12.47	12.85	13.23	13.63	14.04	14.46	14.89	15.34	15.80	16.27	16.76	17.26	17.78
Electric Rate ($/kWh):	0.0568	0.0585	0.0603	0.0621	0.0639	0.0659	0.0678	0.0699	0.0720	0.0741	0.0764	0.0786	0.0810	0.0834	0.0859	0.0885	0.0912	0.0939	0.0967	0.0996
Gas Rate ($/MMBtu):	4.24	4.37	4.50	4.63	4.77	4.92	5.06	5.21	5.37	5.53	5.70	5.87	6.05	6.23	6.41	6.61	6.80	7.01	7.22	7.43
F.C. Gas Rate ($/MMBtu):	4.06	4.18	4.31	4.44	4.57	4.71	4.85	4.99	5.14	5.30	5.46	5.62	5.79	5.96	6.14	6.32	6.51	6.71	6.91	7.12
Fuel Cell Savings																				
Energy Savings ($):																				
Demand:	24,336	25,066	25,818	26,593	27,390	28,212	29,058	29,930	30,828	31,753	32,706	33,687	34,697	35,738	36,810	37,915	39,052	40,224	41,430	42,673
Energy:	89,588	92,276	95,044	97,895	100,832	103,857	106,973	110,182	113,487	116,892	120,399	124,011	127,731	131,563	135,510	139,575	143,762	148,075	152,518	157,093
Displaced Fuel:	18,304	18,853	19,419	20,001	20,601	21,219	21,856	22,512	23,187	23,883	24,599	25,337	26,097	26,880	27,686	28,517	29,373	30,254	31,161	32,096
Subtotal ($):	132,228	136,195	140,281	144,489	148,824	153,288	157,887	162,624	167,502	172,528	177,703	183,034	188,526	194,181	200,007	206,007	212,187	218,553	225,109	231,863
Costs ($):																				
Fuel Cost:	61,915	65,090	68,456	72,029	75,823	79,856	84,146	75,617	79,483	83,581	87,930	92,547	97,453	102,670	108,223	96,218	101,146	106,371	111,916	117,805
Maintenance:	18,000	18,540	19,096	19,669	20,259	20,867	21,493	22,138	22,802	23,486	24,190	24,916	25,664	26,434	27,227	28,043	28,885	29,751	30,644	31,563
Stack Replacement:								126,677								160,471				
Subtotal ($):	79,915	83,630	87,552	91,698	96,082	100,723	105,639	224,432	102,285	107,067	112,120	117,463	123,116	129,103	135,449	284,732	130,030	136,123	142,560	149,368
Annual Savings:	52,313	52,565	52,728	52,791	52,741	52,565	52,248	(61,808)	65,218	65,460	65,583	65,572	65,409	65,078	64,557	(78,725)	82,157	82,430	82,549	82,494
Cumulative Savings:	52,313	104,878	157,607	210,398	263,139	315,705	367,953	306,144	371,362	436,822	502,405	567,977	633,386	698,464	763,021	684,296	766,453	848,883	931,433	1,013,927
Net Present Value:	(134,909)																			
Int. Rate Of Return:	6.3%																			

Waesche Hall

Nearly all of the fuel cell's electrical output could be used assuming that Waesche and Smith Halls can be tied together into one electric bill. Discussions with CL&P revealed an openness to discuss the practical requirements involved. CL&P would need to install a backwards meter as well as charge an additional customer service fee to account for the individual transformers at these two buildings. Electrical savings from the fuel cell were calculated based on it operating at a 90 percent capacity factor and adjusted downward by 5 percent to account for periods when the combined loads fall below 200 kW (Table 22).

Table 22. Electrical savings—Waesche Hall (CL&P Rate 56).

	Displaced Energy	Energy Rate	Savings
Prod./trans. kW	2,400	$5.26	$12,624
Distribution kW*	2,400	$4.26	$10,224
On-peak kWh	713,029	$0.05260	$37,505
Off-peak kWh	784,931	$0.04260	$33,438
Total			$93,791
* 11 month ratchet applies			

The fuel cell thermal output would be used to displace electric space heating in the building. As discussed previously, a total of 522,534 kWh could be displaced by the fuel cell. Factoring in the 90 percent fuel cell availability and adjusted downward 5 percent, the total displaced electricity for space heating would be 444,154 kWh. It was estimated that an additional 40 kW of demand savings (~20 percent) would be displaced by the fuel cell thermal output during the 8 months of space heating demand. Table 23 lists energy savings from displacing electric space heating.

Table 23. Displaced electrical space heating—Waesche Hall.

	Displaced Energy	Energy Rate	Savings
Prod./trans. kW	320	$5.26	$1,683
Distribution kW*	320	$4.26	$1,363
On-peak kWh	211,502	$0.05260	$11,125
Off-peak kWh	232,652	$0.04260	$ 9,911
Total			$24,082
* 11 month ratchet would apply			

Input fuel costs are calculated based on the fuel cell operating at a 90 percent capacity factor and reduced 5 percent due to the combined loads falling below 200 kW. This results in a total of 14,201 MMBtu. Table 24 lists gas costs.

Table 24. Input fuel costs.

Service charge	\$4,200 = \$350 x 12 mo/yr
Demand charge	\$375 = 25 Ccf x \$1.25/Ccf x 12 mo/yr
Commodity charge	\$54,532 = 14,201 MMBtu/yr x \$3.84/MMBtu*
Total fuel cost	\$59,107 = \$4,200 + \$375 + \$54,532
*\$3.84 MMBtu = ((214/365 days/yr x \$0.2833/Ccf) + (151/365 days/yr x \$0.5255/Ccf)) x 10 Ccf/ MMBtu	

The estimated net savings is \$58,766. Factoring in the 11-month ratchet on distribution demand, first year savings would be reduced by \$9,372 (11 mo/12 mo x \$10,224 distribution demand) to \$49,394:

\$58,766 = \$93,791 + \$24,082 – \$59,107

\$49,394 = \$58,766 – \$9,372

Table 25 lists the estimated Waesche Hall fuel cell energy savings for a number of demand reduction scenarios (no space heating demand savings, 50 percent and zero demand savings for building). If no demand savings are achieved through space heating, then energy savings are reduced by only ~\$3,000 per year (\$55,720).

Table 25. Estimated fuel cell energy savings for a number of demand reduction scenarios (Waesche Hall).

Case	ECF	TU	Displaced kWh	Displaced Heat (kWh)	Electrical Savings	Thermal Savings	Nat. Gas Cost	Net Savings
Full Demand Savings								
Space Heating	90%	26%	1,497,960	522,534	$93,791	$24,082	$59,107	$58,766
Space Heating w/o Demand	90%	26%	1,497,960	522,534	$93,791	$21,036	$59,107	$55,720
50% Demand Savings								
Space Heating	90%	26%	1,497,960	522,534	$82,367	$24,082	$59,107	$47,342
Space Heating w/o Demand	90%	26%	1,497,960	522,534	$82,367	$21,036	$59,107	$44,296
Zero Demand Savings								
Space Heating	90%	26%	1,497,960	522,534	$70,943	$24,082	$59,107	$35,918
Space Heating w/o Demand	90%	26%	1,497,960	522,534	$70,943	$21,036	$59,107	$32,872

Assumptions:

Electric Rate: $0.0626 /kWh (Average—See CL&P Rate 56)

Input Fuel Rate: $4.16 /MMBtu (Average—See Yankee Gas Rate 27)

Fuel Cell Thermal Output:700,000 Btu/hour

Fuel Cell Electrical Efficiency (HHV): 36%

Seasonal Boiler Efficiency: 75%

ECF = Fuel cell electric capacity factor

TU = Thermal utilization

As with Roland Hall, an analysis was performed to show the net present value over the life of the fuel cell including maintenance costs, stack replacement costs, cell stack degradation, etc. Base installation costs were increased by $32,500 to account for the three new heat exchangers ($7,500), the additional design required ($10,000), and the installation of piping, pumps and valves ($15,000). Table 26 lists the input assumptions used in the lifecycle cost analysis.

Table 26. Lifecycle cost input assumptions for Waesche Hall.

Capital Cost	$650,000
Installation Cost	$132,500
Maintenance Cost	$18,000/yr
Stack Replacement Cost	$100,000
Fuel Cell Rebate	$200,000
Stack Life	60,000 hours
Cycles per Year	1
Escalation Rates	3% per year
NPV Discount Rate	4%, 10%, 15%, 20%

Using the above input assumptions plus the energy savings shown in Table 24, an IRR of 6.5 percent was calculated for the full demand space heating case. At a 10 percent discount rate, the NPV is –$86,376. Table 27 lists results for several NPV discount rates a second case where no demand savings from space heating were credited. Table 28 lists the lifecycle cost analysis for the full space heating case.

Table 27. Lifecycle cost summary results for Waesche Hall.

Case	F.C. Cost	IRR	NPV@4%	NPV@10%	NPV@15%	NPV@20%
Full	$450k	6.5%	$91,939	–$86,376	–$162,930	–$209,290
Space	$650k	1.9%	–$108,061	–$286,376	–$362,930	–$409,290
Heating	$850k	—	–$308,061	–$486,376	–$562,930	–$609,290
No Space	$450k	5.1%	$38,417	–$118,208	–$185,513	–$226,363
Heating	$650k	0.7%	–$161,583	–$318,208	–$385,513	–$426,363
Demand$	$850k	—	–$361,583	–$518,208	–$585,513	–$626,363

The economic analyses presented for both Roland and Waesche Halls represent a general overview of the potential savings from a fuel cell. Since actual load energy profiles will vary, net energy savings could change depending on actual thermal and electrical use.

Table 28. 20-year lifecycle analysis (Waesche Hall).

Fuel Cell Costs		Fuel Cell Performance		Operation		Financial	
Capital Cost ($/kW)	$3,250	Electrical Efficiency (HHV)	0.36	Equipment Life (Years)	20	Demand Savings ($/yr)	22,848
Installation Cost ($/kW)	$663	Overall Efficiency (HHV)	0.73	Capacity Factor	0.9	Energy Savings ($/yr)	70,943
Maintenance Cost ($/YR.)	$18,000	Cell Voltage (volts/cell)	0.7	Cycles per Year	1	Input Fuel Cost ($/yr)	59,107
Stack Replacement Cost ($/kW)	$500	Cycle Degradation (mV/cycle)	6	Displaced Boiler Efficiency	0.75	Thermal Savings ($/yr)	24,082
Fuel Cell Rebate ($/kW)	$1,000	Operating Degradation (mV/1000 hrs)	2	Thermal Utilization (MMBtu/yr)	1,516.0	Inflation	0.03
		Stack Life (Hours)	60,000			Fuel Escalation	0.03
		Fuel Cell Size (kW)	200			Electric Escalation	0.03
		Months of Demand Reduction:	12			NPV Discount Rate	0.10

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Intermediate Calculations																				
Hours																				
Operation Hours/yr	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884
Total Operation Hours	7,884	15,768	23,652	31,536	39,420	47,304	55,188	63,072	70,956	78,840	86,724	94,608	102,492	110,376	118,260	126,144	134,028	141,912	149,796	157,680
Total Stack Hours	7,884	15,768	23,652	31,536	39,420	47,304	55,188	3,072	10,956	18,840	26,724	34,608	42,492	50,376	58,260	6,144	14,028	21,912	29,796	37,680
Degradation (V)																				
Operating	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0031	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0061	0.0079	0.0079	0.0079	0.0079
Cycling	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060
Net Cell Volts	0.6861	0.6722	0.6583	0.6445	0.6306	0.6167	0.6028	0.6909	0.6770	0.6632	0.6493	0.6354	0.6215	0.6076	0.5937	0.6879	0.6740	0.6601	0.6462	0.6323
Operation Values																				
Electrical Eff (%)	35.3%	34.6%	33.9%	33.1%	32.4%	31.7%	31.0%	35.5%	34.8%	34.1%	33.4%	32.7%	32.0%	31.2%	30.5%	35.4%	34.7%	33.9%	33.2%	32.5%
Thermal Eff (%)	37.7%	38.4%	39.1%	39.9%	40.6%	41.3%	42.0%	37.5%	38.2%	38.9%	39.6%	40.3%	41.0%	41.8%	42.5%	37.6%	38.3%	39.1%	39.8%	40.5%
Demand Disp. (kW)	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Electric Output (MWh)	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8
Thermal Displ. (MMBtu)	1516.0	1516.0	1516.0	1516.0	1516.0	1516.0	1516.0	1516.0	1516.0	1516.0	1516.0	1516.0	1516.0	1516.0	1516.0	1516.0	1516.0	1516.0	1516.0	1516.0
Fuel Input (MMBtu)	15,251	15,566	15,895	16,237	16,595	16,968	17,359	15,145	15,456	15,779	16,117	16,469	16,837	17,222	17,624	15,213	15,526	15,853	16,193	16,549
Average Energy Rates																				
Demand Rate ($/kW)	9.52	9.81	10.10	10.40	10.71	11.04	11.37	11.71	12.06	12.42	12.79	13.18	13.57	13.98	14.40	14.83	15.28	15.74	16.21	16.69
Electric Rate ($/kWh)	0.0450	0.0463	0.0477	0.0492	0.0506	0.0522	0.0537	0.0553	0.0570	0.0587	0.0605	0.0623	0.0641	0.0661	0.0681	0.0701	0.0722	0.0744	0.0766	0.0789
Gas Rate ($/MMBtu)	15.89	16.36	16.85	17.36	17.88	18.42	18.97	19.54	20.12	20.73	21.35	21.99	22.65	23.33	24.03	24.75	25.49	26.26	27.04	27.85
F.C. Gas Rate ($/MMBtu)	3.88	3.99	4.11	4.23	4.36	4.49	4.63	4.77	4.91	5.06	5.21	5.36	5.53	5.69	5.86	6.04	6.22	6.41	6.60	6.80
Fuel Cell Savings																				
Energy Savings ($)																				
Demand	22,848	23,533	24,239	24,967	25,716	26,487	27,282	28,100	28,943	29,811	30,706	31,627	32,576	33,553	34,560	35,596	36,664	37,764	38,897	40,064
Energy	70,943	73,071	75,263	77,521	79,847	82,242	84,710	87,251	89,868	92,565	95,341	98,202	101,148	104,182	107,308	110,527	113,843	117,258	120,776	124,399
Displaced Space Heating	24,082	24,804	25,549	26,315	27,105	27,918	28,755	29,618	30,506	31,422	32,364	33,335	34,335	35,365	36,426	37,519	38,645	39,804	40,998	42,228
Subtotal ($)	117,873	121,409	125,051	128,803	132,667	136,647	140,747	144,969	149,318	153,798	158,411	163,164	168,059	173,100	178,293	183,642	189,152	194,826	200,671	206,691
Costs ($)																				
Fuel Cost	59,107	62,138	65,351	68,762	72,384	76,234	80,330	72,188	75,878	79,791	83,942	88,350	93,033	98,013	103,315	91,854	96,558	101,547	106,841	112,462

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Maintenance	18,000	18,540	19,096	19,669	20,259	20,867	21,493	22,138	22,802	23,486	24,190	24,916	25,664	26,434	27,227	28,043	28,885	29,751	30,644	31,563
Stack Replacement	—	—	—	—	—	—	—	126,677	—	—	—	—	—	—	—	160,471	—	—	—	—
Subtotal ($)	77,107	80,678	84,448	88,431	92,644	97,101	101,823	221,003	98,680	103,277	108,133	113,266	118,697	124,447	130,541	280,368	125,443	131,298	137,485	144,025
Annual Savings	40,766	40,732	40,604	40,372	40,024	39,546	38,924	(76,034)	50,638	50,521	50,279	49,898	49,362	48,653	47,752	(96,726)	63,708	63,528	63,186	62,666
Cumulative Savings	40,766	81,498	122,101	162,473	202,497	242,042	280,966	204,932	255,570	306,091	356,370	406,268	455,630	504,283	552,036	455,310	519,019	582,546	645,733	708,398
Net Present Value	(286,376)																			
Int. Rate of Return	1.9%																			

4 Conclusions

This work has evaluated Roland Hall and Waesche Hall, two buildings at the U.S. Coast Guard Academy, New London, CT, as potential sites for installation of fuel cell technology.

The study determined that Roland Hall's potential fuel cell thermal loads are the DHW and space heating loads. Fuel cell thermal use estimates at Roland Hall ranged from 70 to 81 percent.

Waesche Hall has electric resistance heating for its space heating system. If installed, the fuel cell's thermal interface should tie into the building air handlers using intermediate heat exchangers for "pre-heating" the air delivered to the electric resistance heating coils throughout the building. Thermal use at Waesche Hall was estimated at 26 percent.

Estimated annual energy savings at Roland Hall ranged from $70,313 to $73,054, and at Waesche Hall from $55,720 to $58,766. Note that an 11-month ratchet on the distribution demand portion of CL&P's electric bills would reduce the above savings by approximately $9,100 in the first year of fuel cell operation.

Lifecycle costs showed 20-year IRRs of 4.6 percent to 6.6 percent at Roland Hall and 0.7 percent to 1.9 percent at Waesche Hall based on a fuel cell cost of $650,000 (current cost of fuel cell less $200,000 rebate).

Appendix: Fuel Cell Site Evaluation Form

Site Name: **U.S. Coast Guard Academy** Contacts: **Jim Candee**
Location: **New London, CT**

1. Electric Utility: **Connecticut Power & Light** Rate Schedule: **Rate 58/56**

2. Gas Utility: **Yankee Gas** Rate Schedule: **Rate 27**

3. Available Fuels: **Natural gas, fuel oil #6 (low sulfur), Propane**

4. Hours of Use and Percent Occupied:
   Weekdays _____ Hrs _____
   Saturday _____ Hrs _____
   Sunday _____ Hrs _____

5. Outdoor Temperature Range:
   Design dry bulb temperatures: 9 to 85 °F
   Extremes: 5 to 88 °F

6. Environmental Issues: **No major issues anticipated.**

7. Backup Power Need/Requirement: **A few generators at various buildings at the Academy.**

8. Utility Interconnect/Power Quality Issues: **Multiple meters on outlying buildings. Power quality nor an issue.**

9. On-site Personnel Capabilities: **Boiler plant maintenance personnel.**

10. Access for Fuel Cell Installation: **Easy access from parking lot on south side of Roland Hall. Solar Panels are in the way and would have to be removed near installation. Access from the street, with crane used to lift over 8-ft fence. Traffic may have to be stopped or redirected during installation.**

11. Daily Load Profile Availability: **No data available.**

12. Security: **A fence or extension of cooling tower enclosure wall would be required at Waesche Hall.**

Site Layout

Facility Type: **Boiler Plant** Age: **55 years**

Construction: **Steel/concrete with brick.**

Square Feet: **6400 sq ft**

See Figure 2

Show:

- **electrical/thermal/gas/water interfaces and length of runs**
- **drainage**
- **building/fuel cell site dimensions**
- **ground obstructions**

Electrical System

Service Rating: **4160 V distributed base grid.**

Electrically Sensitive Equipment: **N/A.**

Largest Motors (hp, usage): **N/A.**

Grid Independent Operation?: **No.**

Steam/Hot Water System

Description: **Three boilers (The Bigelow Co.) built in 1957.**

System Specifications: **28,500 lb/hr (2)**
14,000 lb/hr (1)

Fuel Type: **#6 low sulfur fuel oil only, no dual-fuel capability**

Max Fuel Rate:

Storage Capacity/Type:

Interface Pipe Size/Description: **6-in. on condensate return.**

End Use Description/Profile: **Boiler plant delivers 90 psi steam around base: 50 psi in buildings and 15 psi at building application. Make-up water estimated at 100 gal/hr. System recently upgraded with new insulation on deaerator and oil separator, condensate return lines repaired, new steam traps, etc.**

Space Cooling System

Description: **No space cooling at the boiler plant. Air-conditioning at various buildings.**

Air-Conditioning Configuration:
Type:
Rating:
Make/Model:

Seasonality Profile:

Space Heating System

Description: **Space heating loops in individual buildings. Waesche Hall has electric resistance heating.**

Fuel: **#6 fuel oil.**

Rating:

Water supply Temp: **375 °F 90 psi steam.**

Water Return Temp: **170 – 200 °F condensate.**

Make/Model:

Thermal Storage (space?): **N/A.**

Seasonality Profile: **Space heating provided from about 15 October to sometime in May. Large boiler operates in winter; small boiler operates in summer.**

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14. ABSTRACT

Fuel cells are an environmentally clean, quiet, and a highly efficient method for generating electricity and heat from natural gas and other fuels. Researchers at the U.S. Army Engineer Research and Development Center (ERDC), Construction Engineering Research Laboratory (CERL) have actively participated in the development and application of advanced fuel cell technology since fiscal year 1993 (FY93). CERL selected and evaluated application sites, supervised the design and installation of fuel cells, actively monitored the operation and maintenance of fuel cells, and compiled "lessons learned" for feedback to manufacturers of commercially available fuel cell power plants and their thermal interfaces installed at Department of Defense (DoD) locations. This report presents an overview of the information collected at the U.S. Coast Guard Academy, New London, CT, along with a conceptual fuel cell installation layout and description of potential benefits the technology can provide at that location.

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